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THE UNIVERSITY OF ALBERTA

"A STUDY IN SOIL ECOLOGY: SOIL ENVIRONMENT, BACTERIAL AND MEIOFAUNAL DENSITIES IN ALBERTA"

by

© KATHY LYNN MORENCY

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE.

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA
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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A STUDY IN SOIL ECOLOGY: SOIL ENVIRONMENT, BACTERIAL AND MEIOFAUNAL DENSITIES IN ALBERTA".

submitted by KATHY LYNN MORENCY

in partial fulfillment of the requirements for the degree of Master of Science.

Bill McGill
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Date April 18 1980.

ABSTRACT

Soil systems are dynamic and are functionally under the control of reciprocal cause-effect relations between biotic and abiotic soil constituents and processes. It is difficult to delineate the ultimate controlling factor in such a system: substrate, environment, or the combination of the soil environment and substrate accessibility. Two of these factors were quantified in this study; substrate supply and the biological component of three Alberta soils. In addition, an investigation of the disruptive effects of a light crude oil spill on the soil and its biological component, was undertaken by clipping surface vegetation, surface-sealing with paraffin and addition of oil.

Populations of Collembola were 4-, 6- and 8×10^5 m^{-2} in the top 12 cm of a Black Solodized Solonetz, Orthic Gray Luvisol and an Eluviated Black Chernozem, respectively. The respective mite populations were 21-, 40-, and 80×10^5 m^{-2}. Estimations were made of the potential exponential growth rates of bacterial populations expected in these soils under optimal conditions, and unlimited substrate accessibility. These values ranged between 40 and 80% of maximum. Bacterial populations were greatest in those horizons containing the most water-soluble organic matter. The accessibility of substrate was concluded to have a greater effect upon biological activity than amount of substrate.

An examination of the effect of Redwater crude (11.4 l m^{-2}) on properties of a grassland soil demonstrated a significant effect on soil temperature, moisture and mineral nitrogen content. However, the mites and Collembola were not significantly reduced by treatment. Such factors as the decomposition of volatile components of the oil, adsorption of the oil to the soil as well as migration of the meiofauna out of contaminated regions of the soil may have protected them from the deleterious effects of the oil.

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INTRODUCTION

Soil bacteria, Collembola and mites act in conjunction with other members of the soil fauna to release immobilized organic nutrients and develop soil structure. In turn, these organisms are affected by soil characteristics such as pH, moisture, temperature, aeration and nutrient content. By virtue of their activities, the soil microflora and meiofauna modify these soil characteristics. For example, CO_2-evolution as well as the production of gaseous and soluble end-products will alter the pH of the soil solution as well as the gaseous components of the soil atmosphere. These effects would be especially noted at the level of the microsite, and may be undetected by common analytical techniques, unless these particular processes predominate in the soil. Thus, the soil biomass and inanimate components must be considered concurrently.

A consideration of the character of the soil as a habitat for the soil microflora and meiofauna in terms of the atmosphere, water content, soluble salts, and water-soluble organic nutrients may elucidate the factors causing the characteristic distribution of these organisms. Interspecific activities such as predation and production of pheromones (Mertens, 1979) may further modify these distribution patterns.

Because of their intimate association with the soil, the meiofauna provide a suitable indication of alteration of soil conditions by pollution with such products as petroleum hydrocarbons. Addition of petroleum hydrocarbons, will in addition to the introduction of toxic compounds into the soil environment, alter soil atmospheric gases, soil temperature, moisture regime and substrate levels and composition. Thus, an alteration of the soil population in terms of density or species make-up may indicate an intricate reaction of the soil organisms to altered soil environmental conditions.

Thus this is a study which attempts to investigate the soil organisms (bacteria and meiofauna) within the framework of their environment. Environmental parameters which were measured included soil moisture, pH, nitrogen as well as water-soluble nutrients. Addition of petroleum hydrocarbons as well as simulated effects of an oil spill provided a situation in which to study the effects of alteration of the soil character on the soil biomass. The literature review discusses the soil in terms of both a physical and chemical environment, and finally, the effect of the soil microflora and meiofauna upon the physical character and energetics of the soil.

LITERATURE REVIEW

THE SOIL AS A HABITAT FOR SOIL MICROFLORA AND MEIOFAUNA

I. THE PHYSICAL ENVIRONMENT

A. THE SOIL ATMOSPHERE

1. Composition of Soil Gases

Soil gas composition is controlled by a variety of physical and biological processes, occurring simultaneously. The soil atmosphere, in turn, affects the reactivity of soil through its effect on redox potential and aerobiosis. For example, under aerobic conditions oxidative processes predominate: oxidation of ammonium salts and nitrite to nitrate; oxidation of sulfur and its compounds to sulfates; oxidation of endproducts of incomplete metabolism such as hydrogen and methane (Taylor and Ashcroft, 1972). The oxygen tension of aerobic sites is in the order of 0.18 atmospheres, as compared to 0.10 atmospheres for anaerobic sites (Griffin, 1972). Soil microsites are considered to become anaerobic when the dissolved O_2 concentration drops to 3×10^{-6} M (Greenwood, 1961). Greenwood (1961) calculated that soil aggregates greater than 3 mm radius and saturated would have virtually no O_2 at the center.

Under most aerobic conditions, the percentage of O_2 in soil air is comparable to that in the atmosphere at the soil surface. However, the concentration of CO_2 is slightly higher in the soil: 0.25% CO_2 by volume is an acceptable concentration in soil air, as compared to 0.03%

in the atmosphere (Taylor and Ashcroft, 1972). Normally the CO_2 concentration in the soil atmosphere does not exceed 0.5% by volume (Burges, 1967).

2. Factors Controlling the Concentration of Soil Gases

The constitution of soil gases varies with depth, amounts of organic matter, soil moisture, porosity and biological activity.

Two opposing processes act to modify the soil atmosphere: the simultaneous production of CO_2 and consumption of O_2, together with gaseous exchange between the soil and atmosphere. Variations in the soil atmosphere result from differences in the relative rates of these processes. The water content and bulk density of the soil also influence both the amount of gas that can be stored in soil, and gaseous diffusion (Taylor and Ashcroft, 1972). Normally, A horizons contain about 50% of pore space, but soil water may occupy about 30% of the soil volume, leaving only 20% for soil gases.

Two processes are involved in gaseous exchange between the soil and atmosphere: mass flow of gas and gaseous diffusion (Taylor and Ashcroft, 1972). Mass flow results from changes in temperature and barometric pressure; use of soil air by plants; removal and replacement of air due to infiltration of water and subsequent drainage; and by wind action forcing air into and out of the soil.

Air diffuses through soil along partial pressure gradients, the pattern of which is dependent upon soil properties which control gaseous movement. Oxygen and carbon dioxide, respectively, diffuse into and out of soil independently of one another along molecular gradients created by usage of oxygen or production of carbon dioxide (Wood and Greenwood, 1971).

Diffusion of gases is considered to occur primarily via inter-crumb pores. However, gases reach respiration sites via moisture filled pores, or through water films within the soil crumbs (Smith, 1977).

The diffusion flux of CO_2 out of soil (J) can be calculated from the diffusion coefficient (D_s) of CO_2 through soil, the change in concentration of CO_2 between some point in the soil and the air above it (dC) and the distance over which diffusion must take place (dx) using

$$J = D_s \frac{dC}{dx}$$

DeJong and Schappert (1972) reported values for D_s for CO_2 through a heavy clay in Saskatchewan. Using their values and taking a CO_2 concentration of 0.5% at 10 cm in the soil, with 0.03% outside the soil, a CO_2 diffusive flux of about 115 Kg C ha^{-1} day^{-1} is achieved. Comparing this with data summarized in Table 1, it would appear that diffusion will result in removal of most of the CO_2 produced by soil without letting CO_2 concentration accumulate to much more than the normal upper limit of 0.5%.

Gaseous exchange at the soil surface is normally rapid (Burges, 1951). This exchange rate is considerably

TABLE 1. Production of CO_2 by various soils and soil-plant systems

Comments	Kg C ha^{-1} Day^{-1}	Reference
Semiarid grassland, Matador, Sask., July	140	DeJong and Schappert (1972)
Eluviated black Chernozem fallow field, Redwater, Alberta, July	12	McGill and Rowell (1977)
Mills Lake, N.W.T., mixed grasses and sedges on alluvial material, July	23	McGill (personal communication)
Average during month of maximum respiration	43	Krysch (1965) as cited by DeJong and Schappert (1972)
Range in summer respiration rates at arid short grass prairie site (Pawnee, Colorado)	3-35	Hunt (1977)

reduced in soils with a high content of clay because of the very small pore size in fine textured soils, and in sandy soils due to the relatively small amount of pore space (Taylor and Ashcroft, 1972).

Oxygen diffusion rate has been estimated in the range of 10^{-2} cm^2 sec^{-1} for very dry soils, to 10^{-6} cm^2 sec^{-1} in saturated soils (Smith, 1977). Therefore, the diffusion rate is about 10,000 times faster in dry than saturated soils.

3. Response of the Soil Microflora and Meiofauna to Oxygen and Carbon Dioxide

Actinomycetes can tolerate a CO_2: O_2 ratio of 1:1, but, an alteration of this ratio to 3:1 results in a drastic reduction in growth rate (Williams et al., 1972).

Soil-inhabiting mites and Collembola are favored by concentrations of CO_2 and nitrogen, higher than in the atmosphere above the soil (Kühnelt, 1976). Burges (1958) postulated that Schweibia mites may actually use areas of low oxygen concentration as refuge from predators. The migration of mites may be limited by low oxygen concentrations at depth. Little information exists on the oxygen requirements of soil-dwelling microarthropods.

In general, it appears that CO_2 concentrations below 5% are not directly harmful to most soil organisms and that O_2 concentrations above 10 to 15 percent do not inhibit soil organisms. An additional effect of acidity due to CO_2 accumulation must always be kept in mind in addition to the direct effect of the gas itself.

4. Variations in the Constitution of Soil Gases

The constitution of soil gases varies with such factors as soil structure and compaction. For example, anaerobic by-products such as ethylene, methane and nitrous oxide accumulate in soils which have been compacted (Smith and Dowdell, 1974). Ethylene is assumed to be of microbial origin, however, no one particular group has been accredited (Considine _et_ _al_., 1977). Such gaseous components vary greatly throughout a seemingly well aerated soil profile, indicating that they originate from isolated anaerobic sites within the soil and diffuse outwards (Smith and Dowdell, 1974).

Anaerobic end-products such as methane, hydrogen sulfide, volatile fatty acids, alcohols, and aldehydes may affect seed germination as well as root growth (Smith, 1977). Ethylene has been found at concentrations greater than 0.01 ppm in soil (Smith and Russell, 1969); that concentration found to have detrimental effects on seedlings.

Evolution of ethylene was found to be positively correlated with total organic matter content, and under certain circumstances, with pH in the range of 5.0 to 7.3 (Goodlass and Smith, 1978).

Elliott and McCalla (1972) found that the constitution of soil gases varied significantly with soil treatment and moisture content. Table 2 illustrates that a soil beneath a feedlot possessed elevated levels of CO_2

TABLE 2. Data demonstrating variability of soil gases under a feedlot and in a cropped soil (Elliott and McCalla, 1972)

Depth (cm.)	CO_2	O_2	N_2	CH_4	Total
	% Volume				
Feedlot					
31	15.0	9.5	66.0	8.0	98.5
46	12.5	9.5	68.5	8.0	98.5
61	15.0	7.5	65.0	11.5	98.0
76	23.0	4.5	45.0	27.5	100.0
91	18.5	5.0	58.5	18.0	100.0
107	18.0	5.0	57.5	17.5	98.0
122	18.5	5.0	56.5	18.5	98.5
152	21.0	6.0	52.0	20.0	99.0
Cornfield					
31	2.0	18.0	79.0	0	99.0
61	2.0	18.0	80.0	0	100.0
91	2.5	18.0	79.0	0	99.5
122	2.5	18.0	79.0	0	99.5
152	1.0	19.0	79.0	0	99.0

These values are means of data collected over a one year period. Elevated levels of CO_2 in the cropped soil result from irrigation events.

and CH_4; O_2 and N_2 gases are volumetrically decreased. Reduced rainfall, and subsequent soil drying, resulted in a decline in CO_2 and CH_4, suggesting that these gases are produced and accumulate under anaerobic conditions found in a wet soil.

The values of CO_2 in the cropped field were normally in the range of 0.2% to 0.4%, however, they were elevated during a period of irrigation. The authors attribute this rise to the use of oxygen by growing plants and increased anaerobiosis. Note CH_4 was not detected in the cropped soil, suggesting the 'sloppy' conditions of soil under the feedlot, and increased deposition of organic debris initiated CH_4 production.

B. SOIL MOISTURE

1. Soil Water Content

Approximately 50% of the soil volume is pore space (Rapoport and Tschapek, 1967). Pores are rarely completely saturated with water. Only a heavy rainfall, irrigation, or snow melt may produce such a condition in well drained soils unaffected by a high water table. The water regime of a field soil may be represented by the simple equation (Baver, et al., 1972):

$P + I - R = E + D + \Delta W$ where P: precipitation
I: irrigation
R: surface run-off
E: evapotranspiration
D: drainage

(cont'd)

ΔW: change in soil water content
or storage

The above relation embodies the concept of soil as an open system, contiguous with the atmosphere above and the remainder of the lithosphere below, with all components joined by the hydrosphere.

Soil water is usually considered that which may be removed by drying mineral soils to a constant weight at 110^{0}C (Baver et al., 1972). Water within the soil contains solutes, however, these substances are ignored unless directly affecting the factor being analyzed. Water usually empties from the largest pores first, it is held tightly in small pores and in interstices between soil particles.

Several forces act upon water within the soil: those caused by gravitational pull on water; forces associated with the attraction of water for solid surfaces; forces which result from dissolved solutes; as well as forces caused by the attraction of water molecules for one another, especially at air-water interfaces (Baver et al., 1972; Rapoport and Tschapek, 1967). Their effect may be quantified as the amount of energy required to cause flow against these forces, and is considered potential energy, for it is not energy of motion. The forces acting upon soil water are termed gravitational potential, matric potential, osmotic potential, and pressure potential; in total they are called water potential (Baver, et al., 1972). There is no difference between different categories of water potential (Rapoport and Tschapek, 1967).

Pressure applied to the soil using a pressure plate enables the measurement of the water retention capabilities of a soil. Two points on the retention curve of a soil are traditionally of interest: that of 1/3 and 15 atmospheres, those contents of water respectively termed the 'field capacity' and 'permanent wilting percentage' of the soil. It should be noted, however, that these terms are out-dated, especially "permanent wilting point" which depends entirely upon the plant.

2. Response of Microflora and Meiofauna to Soil Moisture

Rapoport and Tschapek (1967) estimate the thickness of the film of water expected to cover soil particles at 1/3 bar and 15 atmospheres pressure, summarized in Table 3. From such data, it was concluded that submerged life is not possible even at field capacity for such organisms as rotifers, protozoa, or bacteria. Since soil animals have a very high surface to volume ratio, and are not submerged, they must survive a desiccating environment, and also be able to exchange gases with the atmosphere. Soil animals must then adapt to constant water loss, or develop membranes which are impermeable to water, but permeable to O_2 and CO_2. However, most biological membranes are more permeable to water than to O_2 and CO_2 and consequently constant exchange of water with the surrounding environment is to be expected. It should be noted that soil animals do not respond to the soil water content directly, but

TABLE 3. Estimate of water film thickness and forces acting upon soil water at 1/3 Bar and 15 Bar moisture content (Rapoport and Tschapek, 1967)

Capillary Pressure (atm.)	Diameter of Pores (µ)	Thickness of Film (µ)	Relative Vapor Pressure (P/Po)	Water Potential (erg cm^{-3})	Water Retention Capacity (%)	Osmotic Pressure (atm.)
1/3	8.7	0.1	0.9993	$-0.33.10^6$	"Field Capacity"	Depends Upon Salt Content
15	0.19	0.01	0.9890	$-15.0.10^6$	"Wilting Point Percentage"	

rather to its availability determined by the forces acting upon soil water. The term water activity is used to designate water availability within the soil and the response of soil organisms to it. The activity of water bears a relation to the relative humidity of the soil atmosphere:

$Av = \frac{RH}{100} = Aw$ Where: Aw = water activity
RH = relative humidity
Av = activity of water vapor

The CEA (critical equilibrium activity) is defined as the Aw which is tolerated by particular organisms; for many terrestrial organisms it is 0.99. Wharton and Arlian (1972) review the CEA's for a number of organisms. To maintain a non-desiccating environment, the relative humidity of the soil atmosphere therefore must be 99% (Wharton and Arlian, 1972). This does not always pertain, thus water must be imbibed or ingested in the food, or may be extracted from unsaturated air (Buxton, 1930; Lees, 1946; Noble-Nesbitt, 1970).

Soil water potential affects not only the desiccation of soil animals, but the mobility and decystation of such organisms as Protozoa. It appears that optimal respiratory activity and mobility of soil organisms exists at near 0.5 atmosphere tension (Aw = 0.9996).

Microorganisms require a relative humidity of at least 85% (McLaren, 1963). Williams *et al.*, (1972) determined that little growth of actinomycetes occured over pF 4 (water potential = -10 atm.; Aw = 0.993; note pF = $\log_{10}\left(\frac{1}{\text{water potential (cm } H_2O)}\right)$). The optimal pF range for soil fungi appears to be from 1.9 to 2.3. However, fungi vary in their response to experimental conditions (Shameemullah, 1971). Below pF 1.9, there is a marked reduction in the number of species which can survive, presumably due to prevailing anaerobic conditions. Above pF 2.3, the reduction in surviving species is gradual. *Trichoderma* sp. and *Penicillium* sp. appear to be tolerant of a wide range of moisture conditions. The phycomycetes, *Gelasinospora*, *Dicocium* and *Phoma* tolerate water-logged soil conditions. Higher soil suctions appear to affect the Phycomycetes most dramatically.

Bacteria and fungi survive adverse moisture conditions through formation of endospores, cysts, conidia, chlamydospores, or sclerotia. However, certain individuals may survive these conditions without the formation of these structures. Soil bacteria are generally more sensitive to low soil water potential than soil fungi (Cook and Paperdick, 1970; Griffin, 1972; Jackson, 1975; Wilson and Griffin, 1975).

The moisture content of the soil is of particular importance to soil mites and Collembola. Under equilibrated conditions, 69% of the mass of their body may be transpired as water or evaporated during each half-life of exchange (Wharton and Arlian, 1972). Half-life is described as that time required for the exchange of one-half of the water content of the arthropod body.

The Collembola differ 100-fold in their ability to resist desiccation. Variation is also seen in the tendency for different life stages to desiccate. The CEA (critical equilibirum activity) is used in place of CEH (critical equilibirum humidity) which represents the lowest Av where an organism can maintain its net water loss at zero, because the former can be used to describe the concentration of water in a solution. This factor becomes imperative when discussing the availability of soil water which may be influenced by the osmotic potential due to dissolved solutes (Wharton and Arlian, 1972). Both the CEA and CT (critical temperature) are used to define conditions for optimal activity of organisms. Wharton and Arlian (1972) list a number of values for CEA of a variety of arthropods, many of which are found within the soil. These values varied within the area of 0.80 to 0.95, but were found as low as 0.58 for Liposcelis rufus (Psocoptera) and as high as 1.00 for Tenebrio molitor, adults. Smaller, unpigmented mites appear to be more susceptible to desiccation, than those found at the soil surface.

Soil water activity not only affects organisms directly but indirectly through controls on diffusion rate of nutrients and 0_2. At low water activity diffusion rate of solutes is reduced while 0_2 diffusion rate slows as water activity and potential increases in soil (Smith, 1977). During soil flooding, capillary pores may offer refuge (Christiansen, 1964) for the soil meiofauna. Trapped air bubbles may also provide a means of respiration during flooded conditions. However, a rising water table may displace these bubbles and may cause drowning.

C. SOIL STRUCTURE

1. Creation of an Environment in the Soil Fabric

The environment of the soil microflora and meiofauna is defined by the soil porosity and interstices which result from the seemingly haphazard arrangement of mineral particles mixed with organic debris in various stages of decomposition.

Small size and short distances characterize the soil habitat. The diameter of most soil particles, of soil organisms and soil pores within aggregates are best expressed in μm. Soil aggregate size is expressed in terms of mm or fractions of mm. Normally 70% of the weight of the soil is in aggregates smaller than 1 mm (Taylor and Ashcroft, 1972). Interstices and channels between aggregates are larger, but, as the size of aggregates declines, so does the size of the pores between them, although total pore space usually increases.

At such small scales heterogeneity is extreme. Soil particles are not distributed uniformly. Clay is present in localized accumulations or domains which may be coated with organic matter to varying degrees (Russell, 1969). Soil minerals, especially oxides of iron may accumulate in various foci, and organic debris sloughed from roots is unevenly distributed.

Anaerobic microsites are likely to be present throughout aerobic soil layers. On the basis of diffusion calculations and data of Greenwood (1961), it would appear that anaerobic sites would be expected at any spot more than 1 mm from an air-water interface. It is, however, at these microsites, having μm dimensions, that the deciding events within soil take place and microflora and meiofauna of soil must function.

Soil micromorphological techniques have been developed to examine and define the soil microstructure. With these techniques, one can observe first-hand, the humification processes as well as formation of organo-mineral complexing and subsequent formation of soil structure (Kubiena, 1964).

Soil structure has been described by Jongerius (1957) as the "physical constitution of a soil material expressed by the size, shape, and arrangement of the solid particles and voids, including both the primary particles combined to form compound particles and the compound particles themselves; fabric is the element of structure which deals with arrangement." Micromorphological techniques describe particular arrangements of particles within a soil, accompanied by arbitrary definitions applied to define structural phenomena. Brewer (1964) reviews these concepts.

2. Relationship of the Soil Microflora and Meiofauna to Soil Structure

Employing micromorphological techniques, Szabo _et_ _al_., (1964) distinguished numerous types of colonizing techniques by soil bacteria and fungi intricately related to microscopic soil structure. These microbial pioneers were present in numbers varying from solitary cells, found on the surface of soil particles, to colonies, variously described as linear, miniature, compact, plate, or cover-like. All of these aggregates were intricately associated with soil particles such as decaying plant debris or nutrient-rich inorganic particles. Microbial 'formations' termed bridge, peg, meniscus, or network acted to bind soil particles together in a variety of ways forming soil aggregates.

The influence of soil structure on size distribution of the meiofauna has been discussed by a number of authors (Weis-Fogh, 1948; Macfadyen, 1952; Bellinger, 1954; Elton and Miller, 1954; Murphy, 1955, Poole, 1961). In general, larger species are found near the soil surface, with smaller species adapted to life at depth. In conjunction with the partitioning of size with depth, those species existing at lower depths have lost their requirement for heavy sclerotization, pigmentation and ocelli. These modifications are highly reduced or absent in species found at lower depth in the soil profile.

The soil meiofauna is dependent upon interstices related to soil structure, and channels created by earthworms and decaying plant debris for penetration into the soil profile. It is likely that unless they can disrupt and move aggregates, a large portion of the volume and surface area of mineral soil horizons may be inaccessible to soil animals.

The soil fauna is not only influenced by the soil structure, but plays an important role in its formation. The enchytraeids are of particular importance in this respect in forest soils. Decaying arthropod feces are consumed by these annelids to produce granular debris; enchytraeids may also pierce earthworm casts, and in instances where earthworms are rare, may function to mold soil particles together (Zachariae, 1964).

It is difficult to differentiate using thin sections alone, the role of meiofaunal fecal pellets in formation of soil structure. The color, shape and measurements of this material varies greatly with the type of food consumed and type of animal (van der Drift, 1964). The fecal pellets of the Collembola Tullbergia and Isotoma are minute, and it is difficult to distinguish between this matter and that translocated by water. However, the habit of pthiracarid mites to follow decaying root channels, enables one to pinpoint their contribution to soil microstructure.

D. SOIL TEMPERATURE

1. Effect of Soil Temperature on Soil Biology

Temperature affects the rate of all biological and biochemical processes. Such effects have been quantified by using a Q_{10} value, the effect a 10^{0}C change in temperature has upon the activity of an enzyme or organism.

Enzymes are characterized by optimum temperature ranges, outside of which, reaction rates fall off rapidly. Soil respiration has been characterized with a Q_{10} of 1.6 to 2.0 within a temperature range of 8 to 28^{0}C (Drobnik, 1962). Thus it is imperative that temperatures must be measured when monitoring any biological function within the soil. Mishutin (1953) stated that above all, soil moisture and temperature affect biological functions to the greatest extent.

Definitions created for organisms growing at low, moderate or high temperatures are often delineated by the discovery of organisms capable of growing under particular conditions. A psychrophilic organism is currently defined as an individual having a maximal growth temperature of 20^{0}C or less (Morita, 1975). Psychrophiles have been isolated from Antarctic waters which have a maximum growth temperature of 10^{0}C or less (Christian and Wiebe, 1974; Morita, 1975). Baross and Morita (1978) have reviewed the literature on organisms which grow at low temperatures, and their requirements. Although few obligate psychrophiles have been isolated from temperate soils, bacteria, fungi and yeasts present are capable of growing at temperatures of 0^{0}C or less. Such bacteria have been isolated from many soils and have been estimated in the range of 4×10^5 cells to 2×10^8 cells per g of dry soil (Baross and Morita, 1978).

Tansey and Brock (1978) reviewed the literature on thermophiles; microorganisms capable of growing in the range of 50°C to 90°C. Most of these are nonphotosynthetic bacteria. Soil and rock may become heated to 60°C or higher. Thermophiles have been isolated from temperate and tropical soils (Alexander, 1961).

Khaziev (1976) found there was a maximum development of microorganisms at 20°C and approximately 60% of the water holding capacity in a podzolized Chernozem under laboratory conditions. Actinomyces readily adapted to soil temperatures up to 40°C.

Armillaria also demonstrated maximal growth rate at 20°C, and a limited growth rate at 5°C and 28°C (Rishbeth, 1978). Variability in its growth pattern was noted under different temperature regimes. For example, this fungus demonstrated an initial rapid growth rate at temperatures near 28°C. At 5°C, Armillaria developed at a slower but steady rate. Such findings indicate the adaptability of such organisms to variability in soil temperature. Malhi (1978) reported a similar climatic adaptation of nitrifiers in Alberta soils.

Soil temperature variability is not only seasonal, but is a function of aspect, plant cover, soil color, soil water content, bulk density, and organic matter content.

The soil meiofauna are poikilotherms, thus are regulated by fluxes in ambient temperature (Chapman, 1971).

Metabolism and respiratory rate are most obviously affected by such variability: the Q_{10} of the α-glucosidase of Schistocerca is 2.25 (Chapman, 1971) while the Q_{10} of Ca elimination of forest-floor microarthropods was 2 over a temperature range of 5 to 25°C (Kowal and Crossley, 1971).

Mitchell (1977) gave evidence for the prolongation of the life cycle of oribatid mites with low soil temperatures, measured in degree-weeks (Σ of mean weekly temperatures between successive life stages). By comparing these values with the total number of degree-weeks in a year, Mitchell determined that the oribatid Ceratozetes gracilis would require from 2.1 to 2.4 years for development from egg to adult. The life cycle of C. gracilis was determined to be complete within 1 year in New York (Hartenstein, 1962) and 41 days at 20^0C (Haarlov, 1960).

Evidence also exists for acclimation of respiratory activity in insects. For example, increased oxygen consumption in response to a temperature rise in Melasoma is related to the ambient temperature of the environment before experimentation (Chapman, 1971). Those organisms preconditioned at lower temperatures demonstrate maximum oxygen consumption at lower temperatures.

2. The Temperature Regime of the Soil

Thermal energy within a soil results from a variety of sources: radiant energy, heat received from the atmosphere, heat from organic residues, and heat from the earth's interior (vados energy). The latter two sources contribute negligibly to the soil's temperature.

Solar radiation is partitioned among a variety of components before reaching the earth's surface: it may be reflected by clouds; absorbed by molecules of carbon dioxide, ozone, or water vapor; or scattered and diffused by dispersed particles in the atmosphere (Baver _et al_., 1972). The energy which eventually reaches the soil is termed net radiation (Chang, 1968), and represents the difference between total downward and upward radiation flux. Approximately 65 to 90% of the solar radiation reaches the soil surface; at this point it is converted to thermal energy.

Thermal energy serves to warm both the soil itself as well as the soil air. The ratio of these two processes results in warming or cooling the soil.

Soil temperature displays a two-fold periodicity: daily and seasonal, with greatest variability in temperature occurring at the soil surface. From this point, heat spreads through the soil as a pulse according to the thermal conductivity of the soil. The expenditure of energy through heat transfer results in decreased temperature maxima at depth and smaller amplitude in the soil temperature wave or pulse.

The thermal conductivity of soil obeys Fourier's law which describes linear heat flow, described by the equation: $q = -ks \frac{t,-t_o}{d}$, where q is the amount of heat flowing per unit of time cal sec^{-1}, s is the cross-sectional area, $t,-t_o$ is the temperature gradient, k is the thermal conductivity (cal/cm sec degrees) and d is thickness (cm). Thus the heat flowing through a soil is directly proportional to its thermal conductivity, cross-sectional area and temperature gradient. The thermal conductivity of a soil varies from 4 cal (cm sec °C)$^{-1}$ for wet sand to 0.11 cal (cm sec °C)$^{-1}$ for dry peat (Baver, et al., 1972).

The thermal diffusivity of a soil is dependent upon its thermal conductivity and specific heat according to the relation $K = \frac{k}{c\rho}$ (Spiegel, 1965). Thermal diffusivity is represented by the variable K, k is the thermal conductivity, c the specific heat and ρ is the density. The greater the value of K, the faster and deeper the heat will penetrate the soil. Thermal diffusivity is highly dependent upon the moisture content of the soil, thus may vary daily. Hay et al., (1978) describes a relation which enables daily calculation of thermal diffusivity for a soil:

$Az_2 = Az_2 \; e \; -\left(\frac{(z_2 - z_1)}{D}\right)$ where $D = \left(\frac{86400K}{\pi}\right)^{\frac{1}{2}}$ damping depth

K= thermal diffusivity between depths z_1, and z_2 (cm sec^{-1}). The values of Az_1 and Az_2 describe amplitudes of temperature curves, defined by sine waves, at depths z_1 and z_2 (cm). The value K represents a mean value described for depths z_1 and z_2. Baver, et al., (1972) cite values for the thermal diffusivity of soils within the range of 12.6×10^{-3} to 1.2×10^{-3} cm sec^{-1} for wet sand or dry peat, respectively.

3. Variability in Soil Temperature

a. Variability With Soil Treatment

Soil temperature varies with factors influencing the amount of energy reaching the soil surface, for example, vegetation. Vegetation affects albedo, penetration of radiant energy to the soil surface, latent heat of evaporation and insulation of the soil against heat loss (Baver, 1972).

Hay (1978) quantified such effects when studying variability in soil temperature with cultivation technique which modify vegetation, bulk density, pore space, and water content. Soils which were direct-drilled had a significantly higher thermal diffusivity than did a normally ploughed soil. Such an effect was attributed to an increased moisture content and bulk density of the direct-drilled soil (1.32 g cm^{-3} as compared to 1.16 g cm^{-3}).

b. Soil Climates of Canada

Canadian soils may be classified according to their pedoclimate using the criteria of soil temperature and water content. The criteria utilized in such a classification system are presented in Table 4.

Malhi and McGill (unpublished data) summarized average monthly soil temperatures for central Alberta over a 10 year period. These data are presented in Table 5.

TABLE 4. Criteria used to describe the soil pedoclimate (Clayton *et al.*, 1977)

i) Temperature classes

Class	MAST*	MSST**	Permafrost	Growing Season	Degree Days	Comments
Arctic	<- 7°C	<5°C	+	No thermal period >15°C <15 days of >5°C	75°C	Permafrost within 1 m of surface.
Subarctic	-7°C to 2°C	5-8°C	+/-	Short; <120 days >5°C	>5°C are <550	Soils with aquic layers remain frozen within control section.
Cryoboreal	2°C to 8°C	8 to 15°C	-	Moderately short-Moderately long 140-220 days >5°C	555 < 1250	Soils with aquic regimes, remain frozen for portion of the summer.
Boreal	5°C to 8°C	15°C to 18°C	-	Moderately short-Moderately long 170-220 days >5°C	1250-1700	Undisturbed soils may/may not be frozen during short part of dormant season.
Mesic	8°C to 15°C	15°C to 22°C		Moderately long-Continuous 200-365 days >5°C	1700-2800	Undisturbed soils are rarely frozen during dormant season.

*MAST=Mean annual soil temperature
**MSST=Mean summer soil temperature

ii) Soil moisture subclasses

Aquic Regimes: Soil saturated for significant periods of the growing season.

- a. Peraquic: Soil saturated for long periods. Soil water table at or within capillary reach of surface.
- b. Aquic: Soil saturated for moderately long periods.
- c. Subaquic: Soil saturated for short periods.

Moist Unsaturated Regimes: Varying periods of intensities + water deficits during the growing season.

- a. Perhumid: No significant water deficits in growing seasons. Water deficits <2.5 cm. CMI*** >84.
- b. Humid: Very slight deficits in growing season. Water deficits 2.5-6.5 cm. CMI 74-84.
- c. Subhumid: Significant deficits within the growing season. Water deficits 6.5-13 cm. CMI 59-73.
- d. Semiarid: Moderately severe deficits in growing season. Water deficits 13-19 cm. CMI=46-58.
- e. Subarid: Severe deficits in growing season. Water deficits: 19-38 cm. (Cool & Cold Regimes) 19-51 cm. (Mild Regimes) CMI 25-45.
- f. Arid: Very severe deficits in growing season. Water deficits >38 cm. (Cool Regimes) >51 cm. (Mild Regimes). CMI 25.

***$\mathrm{CMI} = \frac{P}{P+SM+IR} \times 100$, where P=growing season ppt'n. SM= H_2O available to crops, stored in soil at beginning of season.
IR= irrigation requirement; water deficit.

TABLE 5. Mean annual soil temperature determined for central Alberta at a depth of 10 cm over a ten year period ranging from 1964 to 1975 (Malhi and McGill).

Date	Soil Temperature	Date	Soil Temperature
January	-5.7°C	July	18.2°C
February	-9.9°C	August	17.9°C
March	-3.8°C	September	11.8°C
April	1.9°C	October	4.9°C
May	10.0°C	November	-0.6°C
June	-14.9°C	December	-4.5°C

Soil climates of the Edmonton region are cryoboreal-subhumid to humid. In Canada, such soils occupy 150 x 10^6 ha (Clayton et al., 1977).

II. THE CHEMICAL ENVIRONMENT

A. pH

1. Factors Affecting pH

The reaction of a soil may vary within broad limits. A sphagnum peat may have a pH of 3 to 3.5 whereas the B horizon of a Solonetzic soil may have a pH of 10.7. The pH of a soil reflects the relative amounts of acidic and basic cations adsorbed to exchange sites within the soil, in equilibrium with those in solution.

Soil pH varies significantly with the CO_2 content of the soil atmosphere. A change in CO_2 content of soil air from 0.03% to 5% may drop pH by over 1 unit, a 10-fold increase in hydronium ion concentration. Such a marked effect is usually reduced by the buffering capacity of the basic cations adsorbed on soil colloids. Rode (1962) illustrates the variation of pH with dissolved CO_2 in solution. Dissolved CO2, present as $CO_3^=$ in solution may bring about a dramatic change in pH. However, the presence of Ca^{++} in solution may produce an alkaline reaction, buffering the effect on pH.

An increase in pH may result from inorganic soil components other than Ca^{++}; such a Fe^{++} or Mn^{++} ions. Following submergence for 30 days, Redman and Patrick (1965) observed an increase in soil pH, which they attributed to

NH_3 release and conversion of ferric and manganic hydrous oxides to their ferrous and manganous form with associated release of OH^- ions. Organic matter enhanced this increase in pH.

2. Effects of Soil pH on the Microflora and Meiofauna

The hydronium ion concentration affects the ionic state of solutes thus the availability of nutrients and inorganic ions. Variability in the pH of a medium affects the surface charge on the microbial cells, thus altering cell wall permeability and ability to react to metabolites (Longworthy, 1978).

Bulk soil pH may not be indicative of that at the microsite. For example, the pH of a microsite may be increased by the removal of NO_3^- or $SO_4^=$ by a root, or decomposition of a clump of organic debris. This is consistent with reported isolation of acid-intolerant species from acidic soils (Pugh, 1974).

Wherever a charged surface comes in contact with water, the pH of the surface (pH_s) will be lower than the bulk pH (pH_b). Thus, the optimum pH of an enzyme in solution will differ from that in the soil (McLaren, 1963). Similarly, bacteria and fungi which may be in close contact with soil colloids likely experience a pH lower (possibly by 1 to 2 units) than the soil solution.

Much of the detrimental effect of low soil pH on soil organisms has been shown to result from toxic levels of Al, Fe or other ions (Mutalker and Pletchett, 1966), or other deficiencies of essential elements such as P and Mo (Hutchinson and Hunter, 1970). Soil organic matter also has a strong ameliorative effect on soil pH (Hoyt, 1977). Therefore, pH measurements can be meaningfully interpreted only if one knows the organic matter content of the soil and if the soil is mineral or organic.

Christiansen (1964) states that pH has little effect on soil microarthropods. However, Joose (1970) states that the optimum pH for Collembola is about 6.5. Hutson (1978) found that fecundity and longevity of a number of soil Collembola were altered by pH, these effects were altered by the ambient temperature, as well as the organism involved.

B. SALTS IN THE SOIL PROFILE

Salts within the soil profile are primarily adsorbed to the negatively charged surfaces of clays, organo-mineral complexes, and organic matter. These negative charges result from cation substitution within clay minerals, broken edge bonds or hydrogen ion removal from carboxyl and hydroxyl groups in organic materials (Baver, et al, 1972). This store of adsorbed cations represents approximately 99% of the component cations within the soil, and acts as a buffer to pH change within the system (Thomson and Trosh, 1978). Complexed cations are in equilibrium with cations in solution (approximately 1% of the cations of soil). This equilibrium reaction is relatively slow when compared to diffusive processes occurring in soil.

Thus negatively charged micelles with their complement of cations form the basis for the soil acid-base-salt system. Adsorbed cations are primarily Ca^{++}, Mg^{++}, K^{+}, and Na^{+}; they originate from soil parent materials, ions circulated through plants and animals, or fertilizer additions.

Exchange of adsorbed cations with the soil solution is controlled by the concentration of salts within the soil solution. Salts may be displaced from their adsorption sites by competing cations according to the valency and atomic weight. Displacement occurs in the order of $Na^{+} < K^{+} = NH_4^{+} < Mg^{++} < Ca^{++} < Al^{+++} < Fe^{+++}$ (Kelley, 1924).

1. Transport of Salts Through the Soil Profile

Salinization of the soil profile is intricately related to movement of water (Szabolcs and Lestak, 1967). Salts normally move by mass flow and diffusion. However, on occasion mass flow may oppose diffusion such that, salts may be transported against the direction of the salt concentration gradient (Mel'Nikova _et al._, 1968). Under conditions of identical water and Cl^{-} ion content, these ions are transported from a coarse to a fine-textured soil, particularly under conditions of rapid water flow. These ions are expected to slow down when entering a negatively charged medium.

Capillary rise replaces water lost by evaporation at the soil surface (Hassan _et al._, 1977; Szabolcs and Lestak,

1967) and may cause salt accumulation at the soil surface (Hassan et al., 1977) resulting in a concentration gradient against the flow of water.

The rate and degree of capillary flow is also related to the depth to the water table, contact angle, surface tension and liquid density by the equation $h = \frac{2\gamma\cos\theta}{\rho g r}$ where h=height of capillary rise, θ=liquid-solid contact angle, ρ=density of liquid, g=gravitational constant, and γ=surface tension. Chen and Snitzer (1978) found that dissolved organics, particularly humic and fulvic acids reduce surface tension. Fulvic acids produced the greatest reduction because of the higher charge density and lower molecular weight.

The contact angle $\cos\theta$ can be determined by:

$$\cos\theta = \frac{\gamma_{gs} - \gamma_{sl}}{\gamma_{lg}}$$

where γ_{sl} = γ of solid-liquid interface

γ_{gs} = γ of gas-solid interface

γ_{lg} = γ of liquid-gas interface

The angle of contact decreases with surface tension of a liquid above a certain critical value: that tension required to create a solid-liquid angle of 0 (Zisman, 1964). Below this angle, capillary rise is dependent upon the surface tension of a liquid. Above this critical value, the wettability of a soil is affected significantly by variation in the contact angle and subsequent changes in surface tension. Decreasing the surface tension will improve soil wettability by decreasing the contact angle. Thus dissolved solutes will aid in soil wettability, and may be transported through the soil by these processes.

Solutes may move by convection downward due to gravity or upward due to capillary rise as described above. They may also move by diffusion which is controlled by the difference in concentration between two points. The direction of diffusional movement may be the same as or opposite to movement by convection. Diffusion follows Fich's law:

$$J_x = -D \frac{dC}{dX}$$

where J_x = diffusional flux (moles solute cm^{-3} sec^{-1}), D = diffusion coefficient (cm^2 sec^{-1}), dC = concentration change (moles cm^{-3} soil) over distance dX (cm). Diffusional movement of ions in soil is normally within the range caused by mass flow and is most important in soils when mass flow is slow (Gardner, 1965). Normally in soil, because of exchange reactions, diffusion is more important for cation than for anion movement (Nye and Tinker, 1977).

2. Documentation of Soluble Salts Under Field Conditions

Pringle et al., (1975) documents a wide variety of concentrations of various cations under field conditions. These data are presented in Table 6.

3. Effect of Salts on the Soil Microfauna and Meiofauna

All organisms require the presence of salt in their diet. The presence of salts in elevated concentrations

TABLE 6. Chemistry of a variety of soils in the Slave River Lowland (Pringle *et al.*, 1975)

Degree of Salinization	# Samples	Depth (cm)	pH	E.C. mmhos/cm	Saturation %	Soluble Ions in Solution meq/liter					
						Na	K	Ca	Mg	S	Cl
Low salt content 0-4 mmhos/cm	15	0-10	6.7	1.3±0.4	314	2.4±1.9	1.4	2.4	6.9	2.6	6.1
	15	10-20	6.9	1.4±0.2	120	4.1±3.7	0.5	2.2	5.1	2.9	5.7
	15	20-30	7.9	1.3±0.9	72	5.0±4.5	0.4	2.3	6.2	6.8	7.1
Medium salt content 4-8 mmhos/cm	9	0-10	6.6	2.3±1.2	319	7.6±7.4	1.7	5.1	6.5	10.0	7.8
	9	10-20	7.3	4.5±2.4	122	16.5±15.0	1.4	11.2	17.3	16.0	12.1
	9	20-30	7.6	4.8±2.8	84	20.0±17.0	1.5	11.9	25.0	67.0	16.2
High salt content 8-16 mmhos/cm	3	0-10	6.4	3.8±0.6	409	106.0±3.7	0.9	10.5	12.1	27.1	118.0
	3	10-20	6.8	7.3±2.3	157	25.0±11.0	0.3	23.0	20.5	64.0	35.0
	3	20-30	7.3	9.0±0.4	80	40.0±4.0	20.7	21.3	20.0	85.0	36.0
Very high salt content 16+mmhos/cm	4	0-10	7.3	22.0±22.0	212	101.0±98.0	0.65	25.6	9.9	30.0	100.0
	4	10-20	7.8	21.0±13.0	88	98.0±58.0	0.23	24.0	26.0	61.0	153.0
	4	20-30	8.1	20.0±6.0	64	93.0±56.0	0.27	27.0	22.4	43.0	130.0

creates problems for individuals not adapted to such conditions: proteins may be denatured, and disruption of the ionic balance of the cell along with destruction of cellular structure are common under saline conditions. Metabolic reactions may thus be disrupted as may transmission of potential within the nervous system and dehydration. For smaller organisms, more intricately involved with the soil solution, (bacteria, fungi, protozoa) dissolved salts exert an indirect effect by increasing osmotic pressure resulting in desiccation and plasmolysis.

Some individuals, however, may be adapted to saline environments. Microorganisms exist under such conditions through maintenance of a high internal salt concentration (Kushner, 1978). For example, the K^+ ion may constitute 30% to 40% by weight of the halophilic bacterium Halobacterium halobium (Gochnauer and Kushner, 1971). The gradient of intracellular to extracellular K^+ concentration may be as high as 1000:1. This ion may actually become growth-limiting, and must be supplied in concentrations of at least 1 mg ml^{-1}. Halobacteria also require Mg^{++} and Ca^{++}. Enzymes reacting under such conditions require the presence of high salt concentrations for activity, stability, or both.

Salt concentrations, osmotic pressure and water activity are all interrelated. Osmotic pressure (π) is related to concentration (C) of molecules or ions in solution (since it is a colligative property) by $\pi = CRT$ where R = gas constant (0.082054 l atm $mole^{-1}$ deg^{-1}) and T = temp (°K). Osmotic pressure can also be related to the mole fraction of solvent (water) by $\pi = \frac{-RT \ln X}{\bar{v}}$ where R and T are as previously defined and $\bar{v}$ is the partial molal volume of water (0.1018 l $mole^{-1}$). The value of X is calculated as $X = \frac{n_2}{n_1 + n_2}$ where n_2 = moles of solvent (water) and n_1 = moles of solute molecules or ions if it is ionic (Castellan, 1964). Similarly, water activity is related to dissolved solutes by $A_w = \frac{p}{p_o} = \frac{n_2}{n_1 + n_2}$ where p = vapor pressure of water containing solute and p_o = vapor pressure of pure water. Therefore water activity can be related directly to osmotic pressure by

$$\pi = \frac{-RT \ln A_w}{\bar{v}}$$

From this relation, it can be seen that even a 0.56 molar solution will reduce A_w to 0.99, a value below which microbial activity and some meiofaunal activities start to be affected. Since most accumulations of salts in our soils occur as Na_2SO_4, which yields 3 moles of ions per mole of salt, as little as 0.2 moles of Na_2SO_4 per liter should start to cause some effect in terms of reduced water activity.

Upchurch and Elkan (1977) found that the symbiont _Glycine javanica_ was progressively inhibited by increasing concentrations of salts. Both the rate of nitrogen fixation and the viability of this organism were affected by high salt concentrations (45 mM). Rhizobium sp. is also affected by NaCl. However, equivalent concentrations of KCl (45 mM) were found to be even more inhibitory.

Several authors have investigated the effects of low levels of salt on nitrogen mineralization. However, it is unclear whether these effects are chemical or biological. Nitrification in non-alkaline soils appears to be stimulated by sub-toxic levels of NaCl, Na_2SO_4, and large amounts of $CaCO_3$. The toxic levels of these compounds as determined by a number of authors are illustrated in Table 7. The nitrification capacity of alkali soils was apparently stimulated by $NaHCO_3$, Na_2CO_3, and $CaCO_3$, while $CaSO_4$ had no effect (Brown and Hitchock, 1917).

The addition of two salts to a soil had an antagonistic effect: when toxic levels of NaCl were added in combination with sodium sulfate, the sulfate ion completely masked the effect of the chloride ion to a concentration of 0.25% (Gibbs et al., 1925). A similar effect was noted with Na_2CO_3 (0.05%) and Na_2SO_4 from a concentration of 0.2% to 0.5% Na_2SO_3. When three salts were added simultaneously, the effect was generally stimulating. Note the use of percentage as a measure of concentration makes comparison difficult, it is impossible to determine the moisture regime of the soil and the effect upon osmotic pressure.

TABLE 7. Comparison of toxic levels of salts as determined by a number of authors (Johnson and Guenze, 1968).

Investigator	Compound	Toxic concentration % salt in soil, dry weight basis
Lipman *et al.*, (1912)	Na_2CO_3	0.025%
	NaCl	0.10%
	Na_2SO_4	0.35%
Greaves (1916)	NaCl	0.153%
	Na_2SO_4	0.00059%
	NaCl	0.01%
	Na_2SO_4	4.14%
	$MgSO_4$	0.30%
Brown and Hitchock (1917)	$CaCO_3$	1.5-6.0%
Greaves and Lund (1921)	NaCl	0.023%
	Na_2SO_4	0.00016%

Singh et al., (1969) found that there was no stimulative effect due to low levels of salts on nitrogen mineralization as reflected by CO_2 evolution. This may be an osmotic effect, illustrated by an almost linear reduction in nitrification with increasing osmotic pressure (Johnson and Guenze, 1963). Nitrate accumulates in the presence of salts due to the differential effect of increased osmotic pressure on the successive stages of nitrification. Salts such as NaCl and Na_2SO_4 will also inhibit respiratory activities. Regression analyses reveals that 56% to 96% of this variability is due to an increased osmotic pressure. At -30 bars tension nitrification is reduced to less than 10% of its maximum value, while carbon dioxide evolution may be as high as 60% of its maximum value. The latter activity is probably that of salt-tolerant organisms.

Singh et al., observed the build up of ammonium nitrogen under conditions of elevated salt concentrations. For example, the presence of an increased concentration of calcium in the soil solution induced the release of ammonium from exchange sites on soil colloids. The rate of exchange was highest with the K^+ ion, which surpassed the ability of Ca^{++}, Mg^{++}, and Na^+ to exchange with NH_4^+. He also explained NH_4^+-N build up by the ability of cations to reduce the electric double layer, thus enhancing the exchange reaction. The amounts of NH_4^+-N in solution were increased by Al, Fe, Ca, Mg, K and Na, in decreasing order of magnitude. The amounts of NH_4^+-N present in solution varied with the organic matter content of the soil, apparently due to increased surface area.

Soluble salts affect the soil meiofauna, for example, Gisin (1951) illustrated the succession of a Collembolan population on a calcareous soil converted to an alpine humus soil through calcium leaching. *Onychiurus zschohkei*, and O. *burneisteri* were succeeded by *Tullbergia affinis*, *T*. *quadrispina*, and *Folsomia fimentaria*, which, in turn were replaced by *Willemia anophthalma*, *Onychiurus obsoloni*, and *Arrhopalites principalis*, which are acid-tolerant species. Such an effect may be due to an altered microbial fauna in response to change in the soil pH through the soil profile.

Hutson (1978) found that the fecundity and longevity of laboratory reared Collembola were not affected by salinity up to 8 mmhos cm^{-1}.

Oribatid mites have also been found under saline conditions in a littoral community (Kühnelt, 1976). Those arthropods found under saline conditions are primarily drought-resistant which are able to adapt to conditions with a high osmotic stress and low A_w.

C. SOLUBLE NUTRIENTS WITHIN THE SOIL PROFILE

1. Origin of Soluble Nutrients

Soluble nutrients within the soil milieu ultimately originate from photosynthetic processes, and subsequently, litter deposited at the soil surface by litter fall and within the soil profile by root systems of plants. This debris, and its decomposition products are considered to be a major portion of the soil litter; the relative proportion of each component is dependent upon the vegetative cover. Soil animals contribute to soil organic matter through maceration of debris and deposition of fecal matter and exuviae. Humic materials may originate from microbial sources as well. Epicoccum nigrum and Stachybotrys sp. produce resorcinol-type polymers. Aspergillus sydowi is capable of producing large amounts of p-hydroxycinnamic acid-derived phenols (Haider and Martin, 1970).

Litter may be subdivided into two simultaneously occurring, but independent components: cytoplasmic and structural (McGill et al, 1980). The tendency for a compound to be easily decomposed is determined, in part, by its initial nitrogen content. A deficiency in nitrogen, manifested in a high C:N ratio of the compound, will lead to immobilization of this element within microbial tissue. Those components of soil litter most resistant to microbial degradation are highly carbonaceous materials such as lignin and cell walls. These comprise a portion of the structural component of litter, and require a longer time for decomposition. Their resistance to decomposition is due to their inaccessibility to enzyme attack and to chemical recalcitrance and not solely to deficiency of N. Cytoplasmic materials such as DNA, RNA, smaller molecules, and enzymes are readily utilized by the soil microflora. Exceptions to this rule are the carbonaceous molecules of glycogen and fat storage products, which are also used if sufficient nitrogen is available.

The organic matter of soil may be chemically divided into an acid-insoluble portion (humic acid) (Felbeck, 1971), an acid-soluble portion (fulvic acids) and humin, which is supposedly inert (Schnitzer and Khan, 1972). These vary in their composition. Humic acids contain approximately 10% of their weight as acid-hydrolyzable amino acids, about 2% of weight is α-amino nitrogen (Felbeck, 1971). The major portion of the humic acid molecule is made up of polycyclic aromatics. It is difficult to determine the exact proportion of single ring aromatics, since they may be produced as byproducts of extraction procedures. Humic and fulvic acids differ primarily in molecular size and the proportion of acidic functional groups. Soil fulvic acids have a higher total acidity in comparison to humic acids and humins. Such variation is reflected in the comparative ability of humic and fulvic acids to complex with cations within the soil solution (Schnitzer and Khan, 1972).

Organic nutrients within the soil are often unavailable to soil organisms by virtue of complexing mechanisms, immobilization and adsorption-desorption processes. Organic matter may be protected from microbial attack through formation of organo-mineral complexes. For example, proteins are more resistant to attack when adsorbed to clay minerals, as are inositol phosphates. Adsorption of nucleic acids and inositol phosphates provide an important store of phosphate within the soil (Greaves and Wilson, 1969).

Nucleic acids are rapidly adsorbed to exchange sites of montmorillonite; 98% were adsorbed within a 1-hour period (Greaves and Wilson, 1969). Such adsorption was found to be pH-dependent with maximum adsorption occurring below pH 5. Nucleic acids appeared to be adsorbed onto interlayer regions of the clay: interlayer expansion as measured by x-ray diffraction corresponded to the diameter of the DNA molecule. Adsorption was related to both adsorbate and electrolyte concentration, in particular, Na^+ and K^+. Because the adsorption process occurred in a stepwise fashion, it was suggested that a double layer of nucleic acid may have developed. The stabilization of DNA molecules and other large molecules within the soil may occur by similar processes.

The cation exchange capacity of a soil is also related to its organic matter content, as evidenced by the fact that the CEC of a soil may be considerably reduced by oxidation with hydrogen peroxide to remove organic matter (Dudas and Pawluk, 1971). Physical evidence was given by these authors for adsorption of organic materials to clay surfaces using the scanning electron microscope. No interlayer adsorption of humic materials was observed.

Thus organic solutes available for structural and energy requirements of the soil microflora are regulated by the cationic concentrations of the soil solutions, organic matter content of the soil, the pH of the soil solution, and the clay minerals present.

Humic materials may complex with glucosamines and amino acids, guarding them against attack by microbial enzymes (Bondietti et al., 1972). Glucosamines are common in nature: N-acetyl glucosamine (as a polymer-chitin) is the most common sugar found in fungi, as well as the exoskeleton of Arthropods. Polygalactosamine may be produced extracellularly by Aspergillus parasiticus. One-third of the hyphal wall of the common soil fungi Mucor rouxii is made up of chitosans (Bondietti et al., 1972).

Compounds such as catechol, 3, 4-dihydroxytoluene, and 3, 4-dihydroxybenzoic acid (caffeic acid) are implicated in the reaction of humic acids and glucosamines. Thus, these compounds will reach the soil solution at a rate regulated by the decomposition of humic materials.

2. Requirements of Microorganisms for Substrate

Microbial growth is a function of substrate concentration and growth yield (Monod, 1949) as described by the equation:

$C_e = kc$ where, k=proportionally constant

C_e= total growth

c=amount of substrate consumed

Bacterial growth follows an exponential pattern, related to the substrate concentration by the equation:

$$R = \frac{R_K C}{C_1 + C}$$

where R_K = maximum exponential growth rate
R = achieved exponential growth rate
C = substrate concentration
C_1 = half saturation value (substrate concentration where growth is half maximum)

Modifications of this basic equation have been made to account for endogenous respiration (Herbert, 1961). This equation is particularly useful at low substrate concentrations such as in soil.

$\frac{dx}{dt} = (R-k)\,x$ where k is the rate of endogenous respiration, and x is biomass. The value of k becomes especially important under conditions of low nutrient content.

Uptake of energy-providing solutes from the soil solution appear to have a C_1 value between 10^{-4} and 10^{-5} M (McGill _et_ _al_., 1980).

The available energy supply often limits growth within the soil (Gray and Williams, 1971). Babiuk and Paul (1970) postulated that much of the energy supply available to soil microorganisms is required for maintenance of microbial biomass (endogenous respiration), as exemplified by the relation:

$$\frac{dx}{dt} + ax = Y \frac{ds}{dt}$$

where a = specific maintenance rate (h^{-1})

x = concentration of cells

Y = yield coefficient, in terms of substrate used.

s = substrate coefficient

When there is no growth, $\frac{dx}{dt} = 0$. If the values $0.001h^{-1}$ and 0.035 are substituted for 'a' and 'Y', it is estimated that approximately half of the energy available to micro-organisms is used for maintenance. This has been challenged by Barber and Lynch (1977) who argue that the value of 'a' should be $0.04\ h^{-1}$, in which case the energy available to soil is inadequate even for maintenance of the total soil bacterial biomass. Since soil contains more than bacteria, the system is indeed highly competitive and nutrient-limited.

3. Water-Soluble Organic Matter

Organic nutrients dissolved within the soil solution provide the microbial flora with C and N for energy and structural components. Studies on these substrates usually involve alteration of the soil by sterilization procedures.

Amino acids within the soil solution may be used for both energy and production of microbial biomass (Halvorson, 1972). These compounds may be replenished within the soil solution by excretion or autolytic processes.

Nine extractable amino acids were found by Wainright and Pugh (1975): aspartic acid, glutamic acid, leucine, and tryptophan (in plentiful supply) while serine, phenylalanine, tyrosine and glycine were found less frequently. Putman and Schmidt (1960) state that amino acids rarely exceed a concentration of 2.0 µg g^{-1} soil.

Burford and Bremner (1975) correlated the denitrification capacity of a soil with its total water-soluble and mineralizable carbon content. Two conditions are required for denitrification: anaerobiosis and the presence of mineralizable carbon. Mineralizable carbon was defined as the amount of CO_2-C evolved from 5 g soil with 15 ml of water incubated at 20°C for 7 days. The denitrification capacities of the studied soils were found to be significantly correlated with total organic carbon ($r=0.77$) and water-soluble carbon ($r=0.99$). Mineralizable carbon was significantly correlated with water-soluble carbon. The latter was present at concentrations ranging between 9 and 259 µg C g^{-1} soil. Thus transport through the soil solution provides important flow of energy-rich materials and micronutrients to respiring and metabolizing microorganisms.

III. THE BIOLOGICAL ENVIRONMENT

A. A FUNCTIONAL CLASSIFICATION OF THE SOIL FAUNA

General categories have been established which classify the soil fauna in terms of their vertical distribution, feeding patterns, or water requirements. Kevan (1965) reviewed such a system; the general categories as well as the criteria used to distinguish these groups are summarized in Table 8.

Thus it becomes evident that an organism may be classified within a number of categories. For example, a fungivorous Collembolan, inhabiting the soil litter can be termed a low primary, aerophilous member of the meiofauna, thus indicating its requirement for substrate, an oxygen-laden atmosphere, as well as its size. These categories are not exclusive, in that the soil ecologist must recognize vertical and horizontal migration patterns as well as variability in substrate selection. Organisms may vary in their requirements for food during different stages of their life cycle. For example, dipterous larvae may be present as members of the soil fauna actively degrading soil organic matter, while the adults of this order lead a supraterrestrial existence.

B. PROPORTIONAL DISTRIBUTION

Macfadyen (1957) illustrated the diversity of animals as well as their proportion in a grassland soil (Table 9).

TABLE 8. General overview of a functional classification system for the soil fauna.

Category	Reference	Criteria for Grouping	Comments
Water fauna	Kevan (1965)	Organisms requiring water for their existence, even if only a film.	Includes the microfauna, or all animals <1 µm.
Burrowers		Organisms capable of making their own channels through the soil.	Animals >1 cm in length.
Epedaphon	Gisin (1950)	Inhabiting the soil surface, may enter the soil.	Morphological adaptations to the habit are observed. Gradations also appear: for example, hydrophilous hemiedaphon, mesophilous hemiedaphon, xerophilous hemiedaphon.
Hemiedaphon		Inhabiting litter and fermentation layers.	
Euedaphon		Inhabiting mineral soil.	
Primary feeders		Feed directly on plant material.	
Low primaries		Decaying plant material is used as substrate.	Inconcise description, difficult to determine whether feeding on decayed plant material or, upon the established microfauna.
Secondary feeders		Predators	Include moldes and carnivorous insects. Prey includes Collembola, Acarina, Coleopterous and Dipterous larvae, molluscs and Dermaptera.
Low secondaries		Feed upon animal remains or their feces.	Necrophagous: Beetles and their larvae, fly maggots, mites, some Collembola, molluscs and Nematodes. Copraphagous: lumbricid worms, Enchytraeids, termites, beetles, some Collembola, mites and Nematodes. Dung inhabitants may also be utilizing the established microbial fauna.
Microfauna	Haarlov (1960)	0.001 to 0.100 mm in length.	
Meiofauna		0.100 mm to 1 cm in length.	Collembola and mites.
Macrofauna		>1 cm in length	
Hydrophilous Edaphon		Those requiring a capillary film of water for locomotion.	
Aerophilous Edaphon		Traverse through the air-filled cavities.	Include members of the meso-fauna (meiofauna).

TABLE 9. Diversity of the soil fauna in a grassland soil (Macfadyen, 1957)

Organism	Number m^{-2}
Earthworms	30-2,000
Enchytraeidae	200-20,000
Mollusca	100-8,500
Diplopoda, Chilopoda	900-1,700
Isopoda	100-400
Araneida	180-840
Coleoptera	500-1,000
Diptera larvae	Approx. 1,000
Hymenoptera	200-500
Collembola	10,000-40,000
Acarina	20,000-120,000
Nematoda	1.8-120 million

The population of soil Collembola has been recorded in numbers varying from 5,000 m^{-2} to 200,000 m^{-2} (Wallwork, 1970; Harding and Stuttard, 1974). For example, a Collembolan population under aspen forest litter was found to vary between 12,000 m^{-2} to 32,000 m^{-2} (Wagner et al., 1977).

Persson and Lohn (1977) cited peak populations of Collembola of 200,000 m^{-2} to 300,000 m^{-2} in a variety of climatic regions: Naglitsch, Germany; maritime Antarctica, New Zealand; Japan; Spitzbergen. Algal subformations in Antarctica have supported Collembolan populations of 959,000 m^{-2}.

Mites are present in the soil in densities of 60,000 m^{-2} to 200,000 m^{-2} (Wallwork, 1970; Ghilarov, 1971; Harding and Stuttard, 1974). Mites have often been found to be present in greater densities within the soil (Kevan, 1962), however, there are exceptions to this observation. Thus both groups represent comparable portions of the soil biological community.

C. SPATIAL DISTRIBUTION OF SOIL ORGANISMS

Distribution patterns are an integrated reaction to ecological conditions, and as such are considered of importance when describing the ecological functioning of the soil system. Four factors are generally considered influential in determining the distribution of the mobile soil fauna: water, food, dimension of the interstices; and in the detritus layer, light (Haarlov, 1960).

Hutchinson (1953) proposed that natural aggregations may be of five types: vectorial, reproductive, social, coactive, or stochastic. External pressures such as ambient temperature, humidity, density gradient or air currents may produce a vectorial pattern. Reproductive patterning may result from an offspring remaining in the vicinity of a parent, while social patterning is a function of signals which lead to clumping. Interspecific activity leads to coactive clumping, while random forces acting on a population lead to stochastic patterns. Clumping in soil arthropod communities is usually of the first four types.

1. Vertical Distribution

The upper 10-15 cm of soil are the most biologically active (Murphy, 1952; Bellinger, 1954; van der Drift, 1962; Dhillon and Gibson, 1962; Poole, 1961; Block, 1966; Price, 1975; Marshall, 1974; Mitchell, 1978). The distribution pattern of soil microarthropods varies with the species. For example, some species may be restricted to specific strata within the soil profile (Haarlov, 1960; Kevan, 1962; Mitchell, 1978). It is generally accepted that the soil fauna in the upper soil strata are generally more robust, pigmented, and possess more setae.

Mitchell (1978) observed a vertical partitioning of oribatid immatures and adults in an aspen woodland soil. The nymphs and larvae were concentrated in the F layer of this soil, as compared to the adults in the litter layer.

It was postulated that this was a response to the abundance of fungi in the F horizon.

Anderson (1978) suggests that the feeding patterns of the soil meiofauna are generally nonspecific, there is no significant variation in the gut contents of the majority of soil arthropods. If this is true, then competing organisms must be highly specialized in terms of habitat selection. He found that this was true for the L and H horizons of a number of organic layers (L,F, and H horizons of mull and mor soils). The diversity of the Cryptostigmatid population was significantly correlated with the diversity of the soil habitat as determined by studying thin sections made from gelatin-embedded soil cores. The F horizon provided too complex a habitat to explain population diversity on this basis. The high diversity of microarthropods in agricultural soils may be explained by high plant productivity (Allen et al., 1975).

Seasonal vertical migration of soil microarthropods appear to be modified by the climatic zone of the experimental site. Such migration is especially noted in temperate regions (Glasgow, 1939; van der Drift, 1951; Milne, 1962; Hale, 1966; Usher, 1970; Marshall, 1974). Data supporting this patterning in oribatid mites has been presented by several authors (Riha, 1951; van der Drift, 1951; Wallwork, 1959; Tarras-Wahlberg, 1961; Usher, 1975; Mitchell, 1978) while others have been unable to observe this phenomenon (Lebrun, 1971; Haarlov, 1960; Anderson, 1971).

Luxton (1972) gives evidence that the vertical patterning of oribatid mites may be related to that of the fungal species throughout the soil profile. Although most oribatid species are panphytophagous (Mitchell, 1978) all extracted species, with the exception of *Ceratozetes gracilis* demonstrated definite partitioning in correspondence to one or more species of fungi.

2. Horizontal Distribution

The distribution patterns of soil microarthropods are generally considered contagious. Such distributions have been reported for both Collembola (Poole, 1961a; Milne, 1962; Block, 1966; Usher, 1975) and mites (Mitchell, 1978). Exceptions to this rule have been reported for Collembola by Lasha (1956) and Poole (1961b).

Horizontal distribution patterns of highly mobile species appear to be more diffuse than are vertical patterns (Haarlov, 1960). Most microarthropods have limited mobility, thus tend to aggregate.

Humidity appears to be an important factor in stimulation of both Collembola (Joose and Vanderhoeff, 1974; Usher, 1975) and mites (Mitchell, 1978) to form aggregations. Mitchell (1978) added that these effects are dependent upon the species of mite, temperature and experimental conditions. The life stage of the animal must also be considered (Joose and Vanderhoeff, 1974).

Food source is an important factor in horizontal patterning (Table 10). Joose (1970) found that Collembolan juveniles responded dramatically to food source. Mitchell (1978) determined that the correspondence of the species of oribatid mite to depth of organic matter varied. Kubiková et al., (1976) found that there was a striking similarity in development of Apterygota and soil fungi: both had similar environmental requirements as well as a strong trophic relationship. However, MacMillan (1975) buried a number of microtubes in the soil, and found there was no significant variation in the fungal loads in these tubes and the guts of Collembola found. He concluded that the Collembola may not choose their food.

Usher (1975) suggested that the degree of aggregation of Collembola will increase with its population density. However, interspecific interactions must also be considered. Evidence for interspecific interaction was given for oribatid mites by Mitchell (1978).

3. Seasonal Distribution

Fall and winter peaks have been reported for the soil meiofauna (Haarlov, 1960; Block, 1966; Mitchell, 1978). This may be a manifestation of downward migration in response to cooler temperatures and dessicating conditions as evidenced by variability in the vertical distribution of adults and juveniles (van der Drift, 1951; Karpinen, 1955; Wallwork, 1959).

TABLE 10. Documentation of organic materials observed to have been utilized by the soil meiofauna for substrate.

Substrate	Reference	Organism	Comments
Macrophytophagous Organisms Lichens: Unspecified sps.	Dickinson & Pugh (1974)	Oppianovis, Schaphermaeus, Cryptoribatula C. segnis, Pirnodus aetectiden	Specifically lichenophagous.
Usnea antartica & Halozetes belgicae	Dickinson & Pugh (1974)	Maudheimia petronia (oribatid)	
Pteridium litter	Dickinson & Pugh (1974)	Onychiurus procampatus, Platynothrus peltifer	Present in densities of 50,000 m^{-2} and 13,100 m^{-2} respectively.
Moist, partially decomposed litter: Pinus ponderosa	Hartenstein (1962)	Twenty species of oribatid mites.	Rot wood was consumed at 0, 2, 4 weeks of decay.
Tsuga canadensis	Hartenstein (1962)	Pelops sp., Achiptera	Showed a preference for fresh, dry litter.
Quercus	Dickinson & Pugh (1979)	Phthiracaroid mites. Oribatid mites.	Litter immersed in water. May prefer abaxial surface of the leaf, non-lignified materials are attacked first
	Schaller (1962) Madge (1969)	Hermannia gibba, Nothrus sylvestris, Platynothrus peltifer, Onychiurus armatus	'Feasterfrass' pattern of mastication produced by Collembola and oribatid. mites.
Sambucus, Alnus Carpinus leaves	Madge (1969)	Collembola, Lincarus, and Phthiracaroidea (oribatids)	'Lockfrass': complete perforation of the intervein region.
Pine needles	Jacot (1936, 1939) Murphy (1953) Hartenstein (1962) Hayes (1963) Wallwork (1967)	Steganocarus, Phthiracarus Adoristes ovatus.	Endophagous development of partially decomposed pine needles. Microbial conditioning appears to be necessary. Immature Steganocarus concentrate upon schlerenchyma and endoderm of conifer needles (xyllophagous). Internal debris in order of 1μ to 20μ size. Enzyme trehalose is lacking from macrophytophagous enzyme complement.

TABLE 10. (continued)

Substrate	Reference	Organism	Comments
	Harding & Stuttard (1974)	Collembola	Ectophagous in habit.
Microphytophagous Organisms			
Bacteria:	Kilbertus *et al.*, (1979)	Collembola	Bacteria observed in the SEM microscopic examination of Collembolan fecal pellets. *Orchesella* and *Tomocercus* are surface-dwelling and utilize primarily fungal mycelia. Evidence is given for partial utilization of spores, and hyphae.
Fungi:			
Trichoderma koningii	Hartenstein (1962)	Oribatids	Preference showed by Belbids for *T. koningii*.
Chladosporium chladosporiodes			
Phialophora mustea			*Aspergillus niger* and *Penicillium* sp. repelled all but *Oppia nova*.
Stemphylium sp.			
	Joose (1970)	Mesostigmatids, Cryptostigmatids. Collembola.	Preferences for certain fungi were demonstrated.
		Nothrus biciliatus	Chose one fungi, preference for young hyphae.
		Hypogastrura tullbergia	
Trichoderma viridae	Farahat (1962)	Collembola; Oribatids, Mesostigmatids, Astigmatids.	Both fungal hyphae and spores were selected.
		Achiptera coleoptrata	Preferred only hyphae.
		Oppia, *Sminthundae*, *Phthiracaroidea*	Reduced numbers noted in soils with these fungi.
Mold-softened tissues of acorns	Winston (1956)	*Eupodes* sp. and *Tarsonemus* sp.	
	Hayes (1963)	*Haploderma magnum*, *Phthiracarus niger*	Showed preference for well decayed needles.

IV. THE ROLE OF THE MICROFLORA AND MEIOFAUNA IN THE ENERGETICS OF SOIL ORGANIC MATTER DECOMPOSITION

Soil microflora are believed to be responsible for 75% of the release and dissipation of total plant-assimilated energy (Macfadyen, 1963). Tropical rain forests contribute most litter per unit area, followed by grassland regions, and then by the forested regions of the world (Table 11). The caloric input of litter in similar climatic regions is comparable, no matter what region of the world.

Lousier and Parkinson (1975) reported two nutrient flushes per annum in an aspen woodland in the Kananaskis region of Alberta, Canada. These were coincidental with the highest moisture levels, as well as a flux in the population of animals characterized by short generations (Dash and Cragg, 1972). Thus a greater degree of nutrient mineralization from the organic matter pool might be expected under optimal conditions of soil moisture.

A. Contributions of the Microflora and Meiofauna to Soil Bioactivity

The biomass of the microflora normally exceeds that of the soil meiofauna. Clark and Paul (1970) stated that estimates of the bacterial biomass vary from 33 to 1,000 g m^{-2}, and that of fungi to be about twice that of bacteria in grasslands. Persson and Lohm (1977) estimated that the Collembolan biomass of a grassland soil ranged from 200 to 500 mg fresh weight m^{-2}, corresponding

TABLE 11. The input of the various components of litter in a number of climatic regions of the world.

Vegetation and climatic region	Reference	Annual Litter input g dry wgt. m^{-2}	Caloric input	Comments
Total litter	Bray & Gorham (1964)	224.8±81.8		
Cool temperate climates				
Rootlets, dying	Orlov (1965)	600 (kg ha^{-1})		Coincident with a leaf production of 3,000 kcals/ha.
Temperate zone:	Macfadyen (1968)		900-6,400 kcals m^{-2}	Soil respiration: (ml CO_2 $hr.^{-1}$)
Rough grazing			3,300 kcals m^{-2}	-
Pteridium			4,050 kcals m^{-2}	4,500
Managed grassland			4,200 kcals m^{-2}	4,500
Arable			-	3,200 (2,900-11,000)
Woodland			1,100-6,400 kcals m^{-2}	6,900-10,600
Equatorial forest			30,000 kcals m^{-2}	13,000-16,100
Matador site	Clark & Paul (1970)		5,000 kcals m^{-2}	
Litter	Ghilarov (1971)		cals g^{-1} ash-free dry wgt:	
L horizon			4,865	
F_1 horizon			4,853	
F_2 horizon			4,773	
H horizon			4,989	
Mineral horizons				
0-10 cm			3,319	
10-20 cm			2,704	
20-30 cm			2,251	

Table 11. (continued)

Vegetation and climatic regoin	Reference	Annual Litter input g dry wgt. m^{-2}	Caloric input	Comments
Woody materials				
Large roots			4,880	
Small roots			5,290	
Bark			5,210	
Fungal mycelia			4,808	
Alder-birch woodland (England)	Hughes (1971)		2,450 kcals m^{-2}	Ground vegetation biocontent and net production in a deciduous woodland.
	Stout (1971)	1,680 kg ha^{-1} yr^{-1}		Tropical and subtropical soils (New Zealand, Fiji).
Microfungi	Dash & Cragg (1972)		2,300 kcals m^{-2}	Kananaskis, aspen woodland.
Tree litter: Kananaskis, Canada	Lousier & Parkinson (1975)			Carbon input: (g dry wgt m^{-2})
Aspen leaves		215±40		106
Balsam leaves		35±15	1,180 kcals m^{-2}	18
Total tree leaf litter		250±49	308 kcals m^{-2}	124 (48.4% of dry wgt litter)
Non leaf litter		66	1,488 kcals m^{-2}	32 (48.6% of dry wgt litter)
Total tree litter		316	465 kcals m^{-2}	156
Understory		99±11	1,953 kcals m^{-2}	46 (46.5% of dry wgt litter)
Total litter fall		415		202
Russian aspen forest		250		

to a dry weight of 70 to 170 mg m^{-2}. Mite biomass has been reported in the range of 50 to 1,500 mg m^{-2} (Harding and Stuttard, 1974). However, it is difficult to compare these values to those of the microflora, because depth was not mentioned in the Arthropod measurements. It appears that the microbial biomass is at least an order of magnitude greater than that of the meiofauna.

A knowledge of the contribution of a group of organisms to the total soil biomass does not necessarily represent the contribution these organisms make to the energetics of the soil ecosystem. The relationship of biomass:microbial activity can be determined by the respiration rate or energy requirements of the organism (Clark and Paul, 1970).

The rate of consumption is determined by a number of parameters which transcend taxonomic categories: metabolic rates, energy utilization, and nutrient element economics (Reichle, 1971). All these factors are influenced by variation in the trophic level, in particular, intake, assimilation, respiration, growth, and production. Within trophic levels, these efficiences are similar, no matter what taxonomic group (Reichle, 1971). The number of calories consumed per individual per day is significantly correlated across a number of trophic levels: Acarina, Annelida, Araneae, Collembola, Diplopoda, Isopoda, and Orthoptera. This consumption rate basically conforms to the relation:

$Y = ax^b$ where $Y = \text{cal day}^{-1}$

$x = \text{cal individual}^{-1}$

$a = 0.071$

$b = 0.725$

Bacteria require 5 kcal g^{-1} biomass day^{-1} of a cell N for cellular mantenance; 60 g of bacteria would then require 300 kcal day^{-1} for maintenance energy. An additional 140 g of fungal biomass would increase the requirements of the population to 1,000 kcal day^{-1} (Clark and Paul, 1970). These energy requirements are comparable to annual litter fall of a number of climatic zones. Thus, the energy input through deposition of litter falls short of that required by the microbial population alone. They must be limited in both requirements for growth and reproduction.

In terms of energy flow through the soil ecosystem, the meiofauna plays a minor role. For example, Mitchell and Parkinson (1976) found that oribatid mites processed approximately 6 g m^{-2} of fungi in an aspen woodland soil, or about 2% of the fungal standing crop. They suggested that the estimations of oribatid fungal consumption by McBrayer and Reichle (1971) and of fecal deposition by Hermannia gibba (2.3 g m^{-2} yr) by Bäumler (1970) were too high. Mitchell's estimation of the oribatid contribution to energy flow in soil is similar to the value postulated by Krivolutskii et al, (1976). Butcher et al, (1971) estimated the energy flow through a Collembolan population to be in the order of 5.65 kcal m^{-2} yr. Zachariae (1964) mentioned that mineralization by Collembola in soil accounted for only 5% to 6% of the total. Kowal and Crossley (1971) reported an ingestion of 9.1 mg mor m^{-2} day^{-1}, 1% of the litter, the litter fall of *Pinus echinata* is approximately 1,000 mg litter m^{-2} day^{-1}. The bulk of the saprovores diet originated from the L horizon of the soil (41%), 39% and 21% of the diet came from the F and H horizons, respectively.

Carbohydrases appear to be present in the guts of soil mites. Luxton (1972) reported α-glucosidases were present in the guts of panphytophages and microphytophages. Macrophytophages possessed both a β-glucosidase and a cellobiase. Cellobiases were usually accompanied by a xylanase and chitinase, thus demonstrating an ability to decompose plant structural components. Kilbertus and Vannier (1979) demonstrated the ability of Collembola to degrade fungal hyphae using SEM studies of the fecal pellets. However, the utilization of such debris is not constant, and varies with ecological conditions, life stages (moulting will inhibit feeding activity) (With and Joose, 1971), as well as position in the soil profile (Kilbertus and Vannier, 1979).

Soil microarthropods contribute indirectly but significantly to the mineralization process by comminution and by altering both distribution and competitive ability of microbes. Nef (1957) estimated that comminution of organic debris increased its surface area by 10,000 times. Since most decomposition processes must occur at surfaces, such an increase is of considerable ecological significance. Delamere-Debouteville (1950) noted the development of a 'sol mort' in the absence of saprophagous organisms. Through comminution of litter, organisms aid in the leaching process of organic nutrients, and as such, aid in their transport through the soil profile. They are not significantly involved in mechanical mixing of the organic debris (Ghilarov, 1971). Minderman (1968) described the decomposition of soil organic materials using an asymptotic curve declining to a limiting value: the rate of decomposition (as determined by the slope of the line) being determined in part by comminution by soil arthropods. Witkamp (1960) reported that the movement of Collembola and mites could be followed through a sterile soil column by a trail of germinating spores, thus demonstrating their role in substrate colonization by microbes. Wiggins and Curl (1979) found that fungal spores carried on the setae of Collembola germinated upon both agar and within sterile soil columns. Kilbertus and Vannier (1979) also found viable fungal hyphae in the fecal pellets of Collembola. Parkinson and Visser (1978) found that the feeding preference of a Collembola reduced the competitive ability of a sterile dark fungus grown in culture with a Basidiomycete. Thus the meiofauna may affect both the distribution and competitive ability of the soil microorganisms. Therefore, mineralization of organic debris by the microflora may be strongly controlled by the presence of such organisms.

V. SOIL PERTURBATION BY OIL SPILLS

A. CHANGES TO THE SOIL ENVIRONMENT

1. The Physical Environment

Addition of oil to a soil affects soil temperature, moisture, porosity and aeration. The physical effects of a massive oil spill may be just as devastating as the chemical alteration of the soil. Oil imparts hydrophobic characteristics on a soil (MacKay et al., 1974; McGill, 1976) which can reduce both infiltration of water into the soil and capillary rise of water to the surface. Surface layers of soil may become more permeable to water due to their hydrophobic qualities (Hillel and Berliner, 1974; Toogood, 1977). These horizons dry and become subject to erosive forces.

Hydrophobic soil layers also result from microbial coatings on soil aggregates (Hillel, 1974). Lipid formation is promoted under conditions of high C:N ratio (Raymond _et_ _al_., 1961) such as occurs during hydrocarbon decomposition in soil in the absence of sufficient N (McGill, _et_ _al_, 1980).

The soil surface may develop a crust following burning or volatilization of lighter hydrocarbons. These hydrophobic layers may be transmitted to lower layers during burning (Debano _et_ _al_., 1976). Soil aggregates may become enveloped with these hydrophobic substances. Such a condition, in conjunction with water-logging, and the high oxygen demand of decomposer organisms promotes anaerobiosis (McGill, 1976). Water-logging is especially prevalent in organic soils, where surface crusts further prevent evaporation of water (Nyborg and McGill, 1974).

Oil may increase soil temperature by 1° to 10° C (Hutchinson *et al*., 1974; MacKay *et al*., 1974; Toogood, 1977) due in part to removal of vegetation, which reduces surface reflection of incoming solar energy. Complete sterilization of the soil does not appear to occur at soil temperatures associated with burning (McGill *et al*., 1980).

2. The Chemical Environment

The addition of oil to a soil provides capable decomposer organisms with an energy supply (Jobson *et al*., 1972; Cook and Westlake, 1976). Oils have a varied chemical composition: over 200 compounds were recognized by Dean and Whitehead (1963), less than half of the constituents of crude oil. Gas is present in oil as it emerges from the ground, up to 300 volumes of gas per volume of oil (McGill *et al*., 1980).

Many microorganisms can utilize petroleum hydrocarbons as a carbon and energy source. *Pseudomonas* sp. appears to be the most frequently isolated decomposer of crude oil (Jobson *et al*., 1972). In addition, *Achromobacter* sp, *Alcaligenes radiobacter*, *Aspergillus*, *Bacillus*, *Corynebacterium*, *Desulfvibrio*, and *Micrococcus* have all been implicated in petroleum degradation (Stone et al., 1942; Ellis and Adams, 1961; McGill et al., 1980).

Fixation of atmospheric nitrogen may result in increased total nitrogen in oil-contaminated soils (McGill, et al., 1980). These increases are believed to be in the order of 0.03% total N in a soil with 1% oil by weight (Plice, 1948) and 1.2% total N in paraffin dirt (Davis, 1952).

Oil has a varied effect on soil pH, with both increases and decreases (McGill et al., 1980). Natural gas appears to buffer pH near neutrality (Ellis and Adams, 1961).

Accumulation of trace metals may accompany disposal of industrial oily wastes on soil. Raymond et al., (1976) detected 7,500 ppm Pb in a soil used for disposal of crankcase oil. Concentrations within this range reduce decomposition processes (Jensen, 1977).

B. CHANGES IN SOIL BIOLOGY

The number of soil organisms is decreased by the volatile components of oil (Buddin, 1914). However, organisms capable of degrading the petroleum hydrocarbons reproduce rapidly. Thus, the microbial population may increase, but the diversity of the group may decline (Stone et al., 1942). Such an effect is not long lasting with a single application of oil (McGill et al., 1980).

Both nitrification and ammonification may be inhibited in an oiled soil (Gainey, 1927; Murphy, 1929; Stundl, 1959; Edigarova, 1963). This decline is related to the rate of oil addition as well as time since application. The original nitrification capacity of a soil is eventually restored (Murphy, 1929). Denitrification may increase in an oil-polluted soil in response to both low oxygen tensions and increased available energy supply (McGill et al., 1980).

Collembola were found to be eliminated and the mite fauna reduced by the addition of oil to a soil (Hutchinson et al., 1974)

Burning is commonly used to remove excess oil. Lussenhop (1976) cited a variety of responses of the soil meiofauna to burning of a prairie grassland, primarily in response to increased detritus following burning. No immediate or prolonged deleterious effect was noted relative to burning. However, soil temperature during burning would be considerably lower in this instance, as compared to those produced when burning off excess oil. In such instances, the vegetative cover is completely removed, thus producing a very hostile environment indeed.

RESULTS AND DISCUSSION

PART I. WATER-SOLUBLE ORGANIC MATTER AND THE MICROFLORA AND MEIOFAUNA OF THREE ALBERTA SOILS.

An investigation of three soils: Gray Luvisol, Gleyed Black Chernozem, and a Black Solodized Solonetz was undertaken to determine the organic nutrient content (mineralizable carbon, amino acid nitrogen and total water-soluble carbon) of the soil solution and the bacterial flora and meiofauna of these soils. The nutrients available to the soil biomass may be quantified in terms of water-soluble organic matter, which represents well over half of the readily decomposable organic matter in the soil (Hu *et al.*, 1972; Burford and Bremner, 1975). Variability in the species diversity of a population, as well as its density may be correlated with substrate concentration (Monod, 1949), but, factors such as habitat diversity (Anderson, 1978), must also be considered. Thus, measurements of total water-soluble organic matter in these soils provide some explanation for the variability in numbers of both the microflora and meiofauna in different habitats.

MATERIALS AND METHODS

A. ANALYSIS OF SOILS

1. Population Assessment

a. Bacteria

Moist samples were analyzed within 24 hours of collection. A 2 mm sieve was used to break up the samples, which were then mixed, and a 10 g subsample was removed and utilized for analysis. Serial dilutions were made in sterile water blanks, and a 0.1 ml aliquot was plated on PCA agar to produce a series of dilutions ranging from 10^{-5} to 10^{-7}. Plates were incubated at 30°C for 10 days after which colonies were counted.

b. Fungi

Samples were prepared in Bouin's solution for enumeration using the Jones and Mollison technique (Jones and Mollison, 1948). Limited time forced cancellation of this portion of the study.

c. Soil Arthropods

Soil cores were removed to a depth of 9 cm and divided into 3 cm sections then placed in a Macfadyen high gradient extractor for 7 days (Marshall, 1972). Samples were collected over water, then stored in 95% ethanol.

Collembola and Acarina were enumerated separately. No further taxonomic evaluation was undertaken.

2. Analysis of the Soil

The soils were divided into 3 cm sections for analysis in all cases, except the Ellerslie mineral horizons where friability of the samples prevented such treatment.

a. Dehydrogenase Activity

An attempt was made to evaluate dehydrogenase activity of these soils as a measurement of the oxidative metabolism of their microbial flora (Ladd and Paul, 1973). However, all attempts failed.

b. Water-Soluble Organic Matter Content

Suspensions of 10 g soil in 50 ml of deionized water were shaken for 2 hours at room temperature. Suspensions were then centrifuged at 13,200xg for 20 minutes, except for samples taken from the Solonetzic horizons, which were centrifuged at 27,000xg for 20 minutes. All solutions were then filtered through glass fiber filter paper to remove suspended organic debris. Samples were then frozen prior to analysis. Preceding analysis, samples were thawed and filtered through a 0.2 μm millipore filter; the filter was then washed with enough deionized water to increase the sample to 100 ml.

The soil solutions were then analyzed for total water-soluble carbon (Mebius, 1960); ninhydrin-reactive nitrogen (Moore and Stein, 1954), and anthrone-reactive carbon (Oades, 1967).

i) Anthrone-Reactive Carbon

Anthrone reagent was prepared as a 0.2% (w/v) solution in H_2SO_4 (91% v/v). Five ml of reagent was added to 2 ml of soil solution in an incubation tube, sealed, shaken and incubated in an oil bath for 10 minutes at 100°C. The reaction was stopped in an ice water bath. Samples were compared to glucose standards ranging in concentration from 10 to 100 μg glucose ml^{-1}. Readings were taken at 625 nm, and expressed as μg C g^{-1} (O.D. soil).

ii) Ninhydrin Reactive Nitrogen

The ninhydrin reagent (0.4 g ninhydrin, 0.6 g hydrindantin) was prepared in 150 ml methyl-cellosolve, then mixed with 50 ml acetate buffer. Soil solution (0.5 ml) was added to 1.0 ml of the ninhydrin reagent, shaken 10 seconds, then heated for 15 minutes at 100°C. The reagent:sample solution was then diluted with 10 ml of a 50:50 mixture of EtOH:H_2O and cooled in an ice-water bath. Samples were shaken and read at 570 nm then compared to a leucine standard varying in concentration from 0.4 mM to 2 mM (prepared in citrate buffer at pH 5.1). The NH_4^+-N content of the soil solution was measured by steam distillation with MgO, and potentiometric titration. These values were subtracted from those of the ninhydrin-reactive nitrogen, to give an estimate of amino acid nitrogen only.

iii) Total Water-Soluble Carbon

Five mls of the soil solution were heated with 15 mls $K_2Cr_2O_7$ (0.267 N solution) in a 125 ml erlenmeyer flask on a hot plate for 30 minutes. A reflux system was constructed by placing an inverted 50 ml erlenmeyer in the mouth of the larger flask. The flask was then cooled in a cold-water bath. The solution was titrated with a 0.2 N solution of Mohr's salt (78.390 g of $(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$ and 50 ml conc. sulfuric acid in distilled water, diluted to 1 liter). Phenylanthranilic acid (200 mg N-phenylanthranilic acid in a 0.2% Na_2CO_3 solution) was used as the indicator, giving a color change from violet to bright green.

c. Physico-Chemical Parameters

i) Moisture

Moisture percentages were determined gravimetrically using sieved samples (2 mm). Samples were dried at 105°C for 24 hours.

ii) pH

The soil pH was determined using a 10:1 solution of 0.01 M $CaCl_2$:soil; pH was then measured potentiometrically.

RESULTS

A. THE SOIL

Samples were extracted over the 1977 spring and summer seasons. The soils have been described as follows:

BRETON: Gray Luvisol

The vegetative cover at this site included balsam poplar interspersed with spruce trees, and a ground cover of grasses, sparse cover of dogwood, and moss in low lying regions. There were a number of fallen trees within the area sampled, and the area was often quite wet in the depressions. The area sampled was on the peak of a north-facing slope, and therefore received understory-dispersed sunlight, and in spots, direct sunlight.

BRETON: Gray Luvisol

Horizon	Depth	Description
L	9-6 cm	Undecomposed and semidecomposed aspen leaves and spruce needles. Some grass roots. C:N ratio unavilable.
F	6-3 cm	Semi-decomposed leaves and spruce needles mixed with grass roots which are loose to matted. Abundant fine to very fine roots, randomly distributed. C:N ratio 12:1.
H	3-0 cm	Similar rooting pattern as F horizon. Decomposed fibrous to matted organic matter. C:N ratio 11:1.
AeH	0-3 cm	Dark grayish brown 10YR$\frac{4}{2}$ (moist), SL; platy to granular; friable; plentiful random roots. C:N ratio 9:1.
Ael	3-9 cm	Dark brown 10YR$\frac{4}{3}$ (moist), SL; moderate medium platy; friable to very friable, some plentiful fine and very fine randome and horizontal roots. C:N ratio 11:1.
ABe 2	9-15 cm	Light brown 10YR$\frac{5}{3}$ (moist); LS; weak medium platy; vesicular; very friable; few to very few fine, oblique, random, roots. C:N ratio 11:1.
AB	15-18 cm	Brown 10YR$\frac{5}{4}$ (moist), L to SL; coarse platy to blocky; slightly firm, few medium and fine random roots.
Bt_1	18-21 cm	Brown 10YR$\frac{5}{4}$ (moist, crushed); CL; strong, fine subangular blocky, slightly firm to firm; few fine, random roots. C:N ratio 11:1.

ELLERSLIE: Gleyed Eluviated Black Chernozem

This site is vegetated with balsam poplar, with a thick cover of red ozier dogwood in the understory. The site sampled was flat, and only dispersed sunlight penetrated to the soil surface.

Horizon	Depth	Description
L-F	21-15 cm	Loose duff, partially decomposed balsam poplar leaves, as well as undecomposed leaves and partially decomposed roots. Dark brown; 7.5YR$\frac{3}{2}$, abundant medium fine to very fine random and horizontal roots. C:N ratio 46:1.
FH	15-6 cm	Dark reddish brown 5YR$\frac{3}{3}$ (moist), partly humified and humified organic matter; abundant coarse and medium roots, horizontal; random fine and very fine roots. C:N ratio 31:1.
H	6-0 cm	Dark red brown 5YR$\frac{2}{2}$ (moist); humified, loose rootings. %C and %N are 23.1 and 2.4 respectively, giving a C:N ratio of 29:1.
Ah	0-12 cm	Black 10YR$\frac{3}{1}$ (moist); CL; strong medium granular; slightly firm; common fine and very fine oblique roots; few medium and coarse oblique roots. C:N ratio 15:1.

CHIPMAN: Black Solodized Solonetz

The area studied was covered by native grasses, the terrain was flat and open. During the November sampling period, the soil was frozen to approximately 4 cm with ice present, especially at the soil surface. The area is wind-swept, and was only sparsely covered with snow.

Horizon	Depth	Description
Ah	0-3 cm	Brown $10YR\frac{2}{2}$ (dry); SiL; weakly granular; friable; abundant fine to very fine medium roots. C:N ratio 45:1.
Ahe	3-6 cm	Black $10YR\frac{3}{1}$ (dry); L; weak platy to medium granular, very friable; very abundant, very fine to fine and medium, random roots. C:N ratio 104:1.
Ae-Bnt transition (surface coat)	6-6.5 cm	Brown $10YR\frac{6}{2}$ (dry); flakey or moderately platy; friable. C:N ratio 25:1.
Bnt_1	7-12 cm	Brown $10YR\frac{2}{2}$ (dry); matrix with $8YR\frac{4}{4}$ mottles, fine abundant mottles concentrated along root channels; massive clay; very firm; moderately columnar round tops; massive mesa-structure; plentiful very firm fine random roots. C:N ratio 13:1.

The Chipman soil showed evidence of possible intermittent anaerobiosis by virtue of its mottling pattern. No such evidence is present in the sampled horizons of the Ellerslie and Breton soils. The mottling pattern may have arisen from water accumulated on the "roundtops" for mottling was especially evident in root channels where it may have accumulated.

Soil porosity varies greatly in these soils, for example, movement of soil microarthropods would be comparatively unobstructed in the litter and fibrous humic layers of the Breton and Ellerslie soils. Mobility would be expected to be limited to organisms with a slighter stature in the mineral horizons.

B. THE SOIL ORGANISMS

1. Bacteria

Bacterial numbers can only be discussed in terms of trends due to the high variance of the data collected. It is not possible to compare soils due to the difference in sampling date (Tables 12, 13, 14, 15).

In general, bacterial numbers appear to follow the pattern set by readily utilizable carbon, as opposed to the C:N ratio of the soil solution. For example, the number of bacteria in the LFH horizon of the Breton soil is 100 times greater than that found in the mineral horizon of that soil (Table 14). This is also true for the Ellerslie FH and mineral horizons (Table 12 and 13).

TABLE 12. Biological and physico-chemical parameters measured for the organic horizons of the Ellerslie soil.

Ellerslie (Gleyed Eluviated Black Chernozem)

A. Gravimetric % Moisture

	16/06/77	30/08/77
Depth	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.
(21-18 cm)	34.8±5.9	56.1±7.5
(18-15 cm)	25.5±5.1	63.4±8.0
(15-12 cm)	26.6±5.2	54.3±7.4
(12-9 cm)	33.3±5.8	45.5±6.7

B. pH

	pH
Depth	$\bar{x}\pm$S.D.
(21-18 cm)	7.1±0.3
(18-15 cm)	6.8±0.3
(15-12 cm)	6.7±0.1
(12-9 cm)	6.5±0.3

C. Biological Assessment

i) Bacterial numbers m^{-2}

	16/06/77	30/08/77
Depth	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.
(21-18 cm)	$2.10^{12}\pm3.3 \times 10^{7}$	$2.10^{12}\pm3.1 \times 10^{7}$
(18-15 cm)	$1.10^{12}\pm2.2 \times 10^{7}$	$5.10^{12}\pm7.7 \times 10^{7}$
(15-12 cm)	$2.10^{13}\pm3.9 \times 10^{7}$	$3.10^{12}\pm4.3 \times 10^{7}$
(12-9 cm)	$2.10^{12}\pm3.0 \times 10^{7}$	$2.10^{12}\pm2.6 \times 10^{7}$

ii) Arthropod numbers m^{-2}

	16/06/77		30/08/77	
	#COLLEMBOLS m^{-2}	#MITES m^{-2}	#COLLEMBOLS m^{-2}	#MITES m^{-2}
Depth	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.
(21-18 cm)	$3.10^{5}\pm5.10^{2}$	$1.10^{6}\pm1.10^{3}$	$2.10^{5}\pm5.10^{2}$	$4.10^{5}\pm6.10^{2}$
(18-15 cm)	$2.10^{5}\pm5.10^{2}$	$2.10^{6}\pm1.10^{3}$	$2.10^{5}\pm4.10^{2}$	$8.10^{5}\pm9.10^{2}$
(15-12 cm)	$1.10^{5}\pm1.10^{3}$	$2.10^{6}\pm1.10^{3}$	$4.10^{5}\pm6.10^{2}$	$1.10^{6}\pm1.10^{3}$
(12-9 cm)	$2.10^{5}\pm5.10^{2}$	$3.10^{6}\pm2.10^{3}$	$1.10^{5}\pm3.10^{2}$	$1.10^{6}\pm1.10^{3}$

TABLE 13. Physico-chemical and biological data collected on the Ellerslie mineral (Ah) horizon (17/09/77).

Ellerslie Mineral Horizons

A. Gravimetric % Mositure

Depth	% Moisture $\bar{x}\pm$S.D.
(0-6 cm)	20.0±4.5
(0-6 cm)	16.0±4.0
(0-6 cm)	20.4±4.5
n=4	

B. pH

	pH $\bar{x}\pm$S.D.
(0-6 cm)	6.4±0.3
(0-6 cm)	6.4±0.3
(0-6 cm)	6.3±0.3
n=4	

C. Biological assessment

i) Bacterial numbers m^{-2}

	$\bar{x}\pm$S.D.
(0-6 cm)	$9.10^{9}\pm7.10^{7}$
(0-6 cm)	$3.10^{10}\pm6.10^{8}$
(0-6 cm)	$2.10^{11}\pm8.10^{9}$

ii) Arthropod numbers m^{-2}

Depth	#COLLEMBOLS m^{-2} $\bar{x}\pm$S.D.	#MITES m^{-2} $\bar{x}\pm$S.D.
(0-3 cm)	$2.10^{5}\pm5.10^{2}$	$8.10^{6}\pm3.10^{3}$
(3-6 cm)	$3.10^{5}\pm6.10^{2}$	$3.10^{6}\pm2.10^{3}$
(6-9 cm)	$1.10^{5}\pm3.10^{2}$	$4.10^{6}\pm2.10^{3}$
(9-12 cm)	$6.10^{5}\pm8.10^{2}$	$4.10^{6}\pm2.10^{3}$

TABLE 14. Physico-chemical and biological data collected on the Breton soil.

Breton (Gray Luvisol)

A. Gravimetric % Moisture

Depth	$\bar{x} \pm$ S.D.
(6-3 cm) (LH)	196.4 ± 14.0
(3-0 cm) (LH)	105.8 ± 10.3
(0-3 cm) (Ae)	34.0 ± 5.8
(3-6 cm) (Bt)	25.6 ± 5.1

B. pH

Depth	$\bar{x} \pm$ S.D.
(6-3 cm)	6.0 ± 0.3
(3-0 cm)	5.6 ± 0.2
(0-3 cm)	6.0 ± 0.2
(3-6 cm)	6.1 ± 0.3

C. Biological Assessment

i) Bacterial numbers m^{-2}

	9/05/77
Depth	$\bar{x}$ S.D.
(6-3 cm)	$4.10^{12} \pm 6.10^8$
(3-0 cm)	$2.10^{10} \pm 3.10^7$
(0-3 cm)	$2.10^{10} \pm 2.10^7$
(3-6 cm)	$1.10^{10} \pm 2.10^5$

ii Arthropod numbers m^{-2}

	9/05/77		10/10/77	
	#COLLEMBOLS m^{-2}	#MITES m^{-2}	#COLLEMBOLS m^{-2}	#MITES m^{-2}
Depth	$\bar{x} \pm$ S.D.	$\bar{x} \pm$ S.D.	$\bar{x} \pm$ S.D.	$\bar{x} \pm$ S.D.
(6-3 cm)	$1.10^5 \pm 3.10^2$	$1.10^6 \pm 1.10^3$	$6.10^5 \pm 8.10^2$	$8.10^6 \pm 3.10^3$
(3-0 cm)	$2.10^5 \pm 4.10^2$	$1.10^6 \pm 1.10^3$	$2.10^5 \pm 4.10^2$	$9.10^6 \pm 3.10^3$
(0-3 cm)	$2.10^5 \pm 4.10^2$	$1.10^6 \pm 1.10^3$	$5.10^4 \pm 2.10^{2*}$	$7.10^5 \pm 8.10^{2*}$
(3-6 cm)	$1.10^5 \pm 3.10^2$	$1.10^6 \pm 1.10^3$	$7.10^4 \pm 3.10^2$	$5.10^5 \pm 7.10^2$

TABLE 15. Physico-chemical and biological data collected on the Chipman site.

Chipman (Black Solodized Solonetz)

A. Gravimetric % Moisture

	19/07/77		20/11/77
Depth	$\bar{x}\pm$S.D.	Horizon:	$\bar{x}\pm$S.D.
(0-3 cm)	37.0±6.1	Ae	22.8±4.8
(3-6 cm)	33.8±5.8	Bnt	23.6±4.9
(6-9 cm)	32.9±5.7	n=4	
(9-12 cm)	33.4±5.8		
n=6			

B. pH (0.01 $MCaCl_2$)

	19/07/77
Depth	$\bar{x}\pm$S.D.
(0-3 cm)	6.8±0.3
(3-6 cm)	6.9±0.3
(6-9 cm)	6.9±0.3
(9-12 cm)	7.0±0.3
n=6	

C. Biological Assessment (Chipman: Black Solodized Solonetz)

i) Bacterial numbers m^{-2}

	19/07/77		
Depth	$\bar{x}\pm$S.D.	Horizon:	$\bar{x}\pm$S.D.
(0-3 cm)	$7.10^{12}\pm5.10^{11}$	Ae	$5.10^{12}\pm7.10^{11}$
(3-6 cm)	$4.10^{12}\pm4.10^{11}$	Bnt	$4.10^{11}\pm1.10^{11}$
(6-9 cm)	$2.10^{12}\pm2.10^{11}$		
(9-12 cm)	$4.10^{12}\pm4.10^{11}$		
n=6 (x5 analytical reps)		n=4 (x5 analytical reps)	

ii) Arthropod numbers m^{-2}

	19/07/77			20/11/77	
	#COLLEMBOLS m^{-2}	#MITES m^{-2}		#COLLEMBOLS m^{-2}	#MITES m^{-2}
Depth	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.	Horizon:	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.
(0-3 cm)	$1.10^5\pm3.10^2$	$8.10^5\pm9.10^2$	Ae	$4.10^4\pm2.10^2$	$2.10^5\pm4.10^2$
(3-6 cm)	$9.10^4\pm3.10^2$	$5.10^5\pm7.10^2$	Bnt	$2.10^4\pm2.10^2$	$2.10^5\pm4.10^2$
(6-9 cm)	$1.10^5\pm3.10^2$	$4.10^5\pm7.10^2$	n=12		
(9-12 cm)	$1.10^5\pm3.10^2$	$4.10^5\pm6.10^2$			
n=6					

Moisture levels must also be considered, especially in terms of the bacteria and meiofauna. The distribution patterns of the bacterial population also follows that of soil moisture.

2. Microarthropods

Microarthropods are limited in their distribution by substrate, physico-chemical characteristics of the soil, and structure of the habitat.

One would expect the structural limitation of the Chipman soil to hinder the establishment of an arthropod fauna (Table 15). However, the population of this soil consists of larger, more robust individuals of Collembola and mites.

The number of Collembola and mites appear to be evenly distributed throughout the soil profiles examined (Tables 12, 13, 14, 15). The vertical distribution patterns might best be studied in terms of size distribution of the Collembola and mites throughout the soil horizons.

C. WATER-SOLUBLE ORGANIC MATTER

The data obtained for water-soluble carbon are highly variable (Table 16). This variability may represent the variation in substrate levels at the numerous microsites in the soil. However, this high variance in total water-soluble carbon may also be due to technique. For example, the apparatus utilized may have allowed the escape of $K_2Cr_2O_7$ from the system, thus reducing the oxidation of

TABLE 16. Variation in the total water-soluble, anthrone-reactive carbon and ninhydrin reactive nitrogen in the soil solution of the Ellerslie, Breton and Chipman soils.

		Total water-soluble carbon (μg C/g O.D. soil)	Anthrone reactive carbon (μg C/g O.D. soil)	Ninhydrin reactive nitrogen (μg N/g O.D. soil)	
		$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	*C:N ratio
Ellerslie Mineral	(Ah)	1401.96±1176.61	2.5±2.3	0.30±0.55	8.3:1
Ellerslie LFH					
	(21-18 cm)	2791.26±2917.01	23.2±38.5	4.79±2.19	4.8:1
	(18-15 cm)	1051.70±1052.73	55.5±65.2	1.43±1.20	38.8:1
	(15-12 cm)	1969.14±648.46	30.3±30.3	0.93±0.96	32.6:1
Breton					
	(3-0 cm)	6259.94±2608.90	169.6±183.90	1.07±1.04	159:1
	(0-3 cm)	652.88±11.59	56.34±49.57	0.86±0.93	65.5:1
	(3-6 cm)	915.03±414.87	30.09±1.73	0.28±0.53	108:1
Chipman					
	Ae	812.04±363.02	16.89±19.15	0.09±0.30	188:1
	Bnt	1631.40±1469.72	16.14±13.55	0.40±0.66	40.4:1

*Comparison of anthrone-reactive C to ninhydrin-reactive nitrogen.

carbon in the sample. The $K_2Cr_2O_7$ also decayed under the conditions of analysis. This decay rate, and loss of oxidant from the system may have occurred to a variable extent, and thus, could not be accounted for by comparing a heated and cold blank. The reductant, ferrous ammonium sulfate, can be oxidized under laboratory conditions. All these factors reduce the sensitivity of this procedure. However, it was the best technique available at the time of analysis.

Jackson and Hall (1978) indicate that the soil solution extracted from soil cores, as opposed to the slurry method can more accurately reflect changes in the concentration of solutes in the soil solution.

The water-soluble carbon content varies with the soil, as well as the soil horizon. For example, Hu et al., (1972) found that the levels of water-soluble carbon were greatest in less decomposed organic horizons which agreed with the findings of Dickinson and Pugh (1970). Hu found values of water-soluble carbon varying from 6.0×10^4 μg C g^{-1} organic materials (red oak, red maple, white pine litter) to 6,000 μg C g^{-1} organic material (hemlock - yellow birch litter). However, Hu et al., (1972) used a 1:10 solution of soil to water; values for water-soluble carbon would be expected to be higher than those found in a 1:5 soil:water solution. Burford and Bremner (1975) found that total water-soluble carbon varied in the range of 9 to 259 μg g^{-1} of soil. Jenkinson and Powlson

(1976) found values of organic carbon in the range of 160 µg C g^{-1} soil. Thus, the values found in the three studied soils vary within the range of values of total water-soluble carbon reported in the literature (Table 16). The highest amount of total water-soluble carbon was found in the L horizon of the Breton soil: 6,259.94 µg C g^{-1} O.D. soil. This value compares to that found by Hu _et_ _al_., (1972) in the hemlock-yellow birch litter. There is a ten-fold decrease in the total water-soluble carbon content of the underlying horizon of the Breton soil. This is to be expected because of the eluviation occurring in this horizon and because of bulk density changes. Such a reduction in water-soluble carbon is also noted in the Ae horizon of the Chipman site.

The values obtained for total water-soluble carbon were utilized to compare the relative abilities of the respective microbial populations for growth under optimum conditions and the substrate levels provided (Table 17). By utilizing the equation $\frac{R}{R_k} = \frac{C}{C_1 + C_1}$, rearranged from that of Monod (1942), the proportion of maximum growth rate can be determined at the concentration of substrate C, using the value C_1 = 35 µg C ml^{-1} (McGill _et_ _al_., 1980). The greatest capacity for growth is found in the L horizon of the Breton soil, which is 86%. The lowest growth rate would be expected in the Ae horizon of this soil, a value of $\frac{R}{R_k}$ of 48% was calculated for this soil.

It must be realized that these growth rates represent those expected under optimum conditions. However,

TABLE 17. A comparison of the total water-soluble carbon in the Ellerslie, Breton, and Chipman soils and accompanying values of $\frac{R}{R_k}$ as a measure of potential growth of soil bacteria in these soils under optimum conditions.

Sample Horizon	O.D. wgt of soil (g)	μg C ml^{-1}	μg C g O.D. $soil^{-1}$	$\frac{R}{R_k}$*	% R_k
Ellerslie					
(LFH) (21-18 cm)	6.41	178.92±186.98	2791.26±2917.01	0.84	84
(18-15 cm)	5.86	59.52±61.69	1051.70±1052.73	0.63	63
(15-12 cm)	6.48	127.60±42.02	1969.14±648.46	0.79	79
Ellerslie Mineral					
(Ah)	5.60	78.51±65.84	1401.96±1176.61	0.69	69
Breton					
(LF) (3-0 cm)	3.37	210.96±87.92	6259.94±2608.90	0.86	86
(Ae) (0-3 cm)	4.86	31.73±5.63	652.88±11.59	0.48	48
(Bt) (3-6 cm)	6.12	56.00±25.39	915.03±414.87	0.62	62
Chipman					
(Ae)	8.14	66.10±29.55	812.04±363.02	0.65	65
(Bnt)	8.09	131.98±118.90	1631.40±1469.72	0.79	79

C_1 = 35 μg ml^{-1}

* $\frac{R}{R_k}$ = achieved growth as a proportion of maximum.

in the soil, a variety of factors reduce the availability of solutes. For example, soil and environmental characteristics which affect the ψ of soil water will thus affect availability of solutes: soluble salts would affect the osmotic pressure of the soil solution, and may also precipitate organic constituents. The matric potential of the soil water is affected by the structural components of the soil. Adsorbtion-desorbtion equilibria between the soil organo-mineral complexes and the soil solution will also affect the rate of dissolution and of diffusion of organic substrates, and hence their availability to the microbial flora. The physical structure of the microsite will affect the amounts of water present within that environment, for example a large pore is easily drained, while capillary pores resist loss of water to a greater extent. Thus, cell production within soil under even ideal conditions, is limited by substrate concentration and can be expected to be even further restricted by diffusional and environmental constraints which reduce substrate and organism mobility.

These considerations do not account for interspecific competition such as predation, or competition for substrate or cell death and lysis. Thus, the microbial biomass may just maintain itself under conditions in the soil, with major growth fluxes only under periods of optimal substrate input: increased moisture levels, or litter deposition.

The readily mineralizable carbon content of these soils follows the same trend as the total water-soluble carbon. For example, it is most abundant in the LF horizon of the Breton soil. This C-pool is available for energy requiring reactions (Burford and Bremner, 1975). Marumoto _et al_ (1977) demonstrated that microbial cells, in particular, cell wall components (Marumoto _et al_., 1977), contribute up to 24% of the readily-decomposable organic carbon (as measured by CO_2 evolution) in an artificial soil with a C:N ratio of 40:1. This contribution would be expected to be much lower in natural soils where organic nutrients are dissolved from deposited and degrading organic debris. Fluctuations in this component may also occur due to freezing (Ivarson and Sowden, 1976).

Ivarson and Sowden (1976) isolated a number of amino acids from soil, and found the greatest quantities in organic soil horizons (1.15 μg amino acid g^{-1} O.D. soil) as compared to mineral soil horizons (0.06 to 0.12 μg amino acid g^{-1} O.D. soil). Ladd _et al_., (1976) found quantities of amino acids in the range of 22 μg leucine equivalents g^{-1} soil. However, these amino acids were extracted with tris buffer, which might explain the increase in the extraction rate. The Ellerslie LFH horizon contained the most ninhydrin-reactive nitrogen. This may be an indication of the increased input of microbial protein in the well decomposed LFH horizon.

The C:N ratio of the water-soluble components indicate conditions for the net immobilization of nitrogen. Park (1975) indicates that the bulk C:N ratio is not indicative of that at a microsite. For example, the C:N ratios calculated for total water-soluble carbon and ninhydrin-reactive nitrogen are exceedingly high. The C:N ratio at the microsite may be much lower than that indicated by the bulk C:N ratio.

These data indicate that conditions within all three sites are nutrient and energy-limiting, and that conditions for acquisition of substrate are highly competitive.

DISCUSSION

The habitats chosen for this study provide heterogeneity in terms of substrate composition and availability in the soil, as well as habitat diversity. For example, habitat varies throughout the profiles of the particular soils from the L,F and H horizons of the Ellerslie and Breton soils to the highly compacted Bnt horizon of the Chipman site. The former horizons would provide adequate porosity for the aeration of the microsites, as well as diversity of microsites for the microflora and meiofauna. A gradation into sites of more limited accessibility is also present. The A and B horizons of the Ellerslie and Breton soils would be limited to those organisms capable of traversing the restricted pore space and channels created by larger organisms. The Bnt horizon would be expected to exclude all organisms, thus restricting organisms to only cracks and fissures. However, to provide proof of the presence of organisms in this compacted horizon, these samples should have been separated from the Ahe horizon at the point of sampling.

Under non-restricted solute supply, it appears that there is adequate substrate to support the growth of microflora in all soils analyzed. However, when one considers factors such as osmotic potential, matric potential and physical inaccessibility of the substrate, as well as diffusional constraints, it appears microbial growth within the soil is limited by substrate accessibility, rather than lack of nutrient.

PART II. THE ELLERSLIE OIL EXPERIMENT

This portion of the study was undertaken to investigate some effects of an oil spill on the soil meiofauna. Effects of oil pollution upon invertebrates are well documented (Hutchinson et al., 1974). However, little work has been done on the effect of petroleum hydrocarbons upon the population of soil animals. Hutchinson et al., (1974) document a dramatic decrease in both Collembola and mites due to severe contamination of peat by oil.

An attempt was made to separate the effects of an oil spill: removal of vegetation, presence of oil, and surface crusting. These effects would be expected to dramatically affect soil aeration, nutrient content, water regime, as well as introduce toxic compounds. The soil Collembola and mites are intricately associated with the microstructure of the soil, and are dependent upon this environment for their air supply, nutrients, moisture and physical protection. Thus, these organisms should provide a useful indication of altered soil conditions as a result of pollution by oil.

MATERIALS AND METHODS

A. ANALYSIS OF SOIL

1. Sampling and Extraction of Collembola and Mites

The soil cores used for extraction of Collembola and mites had a volume of 28.26 cm^3. Samples were initially taken using a Macfadyen split core, however, difficulties arose due to the break-up of samples; a tulip-bulb planter replaced this equipment.

During the 1976 sampling season, samples at the 3-6 cm depth were utilized to compare treatments; microarthropods were extracted as previously mentioned. This depth contained the greatest number of organisms during preliminary sampling. Coincident with this extraction, samples were also taken to a depth of 9 cm (and divided into 3 cm intervals) in the control plot and one treatment plot. In this manner, it was hoped to gain some insight into the vertical distribution pattern of the soil microarthropods.

During the 1977 sampling season, another Macfadyen extractor was made available and all samples were taken to a depth of 12 cm and divided into 3 cm sections, to give an indication of the vertical distribution of Collembola and mites.

Each sample was placed in a plastic bag and stored under refrigeration (4°C) for approximately 24 hours after which they were extracted. Samples were extracted over water, and stored in 95% ethanol.

2. Physico-Chemical Analysis of Soil

a. Soil Moisture

Soil moisture was done gravimetrically.

b. Temperature

Temperature readings were taken at weekly and bi-weekly intervals during the first sampling season; monthly readings were taken during 1977.

A thermistor was employed to take each reading at a depth of 3-6 cm during the first season, and at 3 cm increments to a depth of 9 cm during the second sampling season.

c. Mineral Nitrogen

Moist 10 g samples were shaken for 30 minutes with 2N KCl. The solution was then utilized for determination of NH_4^+ - N and NO_3^- - N using steam distillation as outlined by Bremner (1965).

d. pH

Soil pH was determined in 0.01 M $CaCl_2$ using a 10:1 solution: soil ratio. Soil pH was measured potentiometrically.

EXPERIMENTAL DESIGN

Treatments were applied in May of 1976 to a permanently grassed site on the University of Alberta farm at Ellerslie. Chemical and physical analysis of the soil commenced immediately. Examination of the soil for Collembola and mites began approximately one month later.

Plots were 1 m^2, and were surrounded by a 1 m buffer zone. The plots were arranged in a stratified random design. Each treatment was replicated 4 times.

The treatments were termed "CONTROL", "OIL", "PARAFFIN", and "NO VEGETATION" and were applied as follows:

OIL: Redwater crude oil was applied at a rate of 11.37 liters m^{-2}. Large (260 ml) juice cans were perforated at the bottom and used to apply the oil evenly.

PARAFFIN: Sealing wax was heated and applied evenly over the soil surface. This treatment was used to simulate surface crusting.

NO VEGETATION: An oil spill effectively destroys non-tolerant vegetation. This treatment simulated this effect. Vegetation was removed using hand clippers and raked off the site.

STATISTICAL ANALYSIS

Factorial analysis of variance was utilized to analyze the physico-chemical data obtained. The data obtained for the 1977 sampling season were analyzed using the SPSS package. Duncan's new multiple range test was used to group data, when the F ratio indicated significance.

Factorial analysis of variance was used to determine the effect of treatment on the Collembola and mites in most cases. However, a T-test was used to compare the control soil and the "oil" (Table 26) and "no vegetation" (Table 25) treatments at depth.

The data used for statistical analyses were not transformed. Abrahamsen (1972) stated that transformation is unnecessary, because analysis of variance is robust against non normality. He further stated that transformation may impede interpretation of results.

RESULTS

A. SOIL MOISTURE

During the first sampling season, there was significant effect of treatment on soil moisture ($p = 0.01$) due to treatment and sampling date (Table 18). Utilization of an LSD revealed the soil treated with oil was significantly wetter than the control soil. A Duncan's new multiple range test revealed that the June 30 and July 9 sampling dates were drier in comparison to other sampling dates and the May 5 and June 7 samples were significantly wetter. The effect of treatment continued into the 1977 sampling season (Table 19). During the second season, variability was also noted in the moisture content of the soil with depth ($p = 0.01$).

The values for 31 bar, 15 bar and 1/3 bar moisture percentages for the Ellerslie soil are 11%, 24% and 44%, respectively (unpublished data). Thus, it appears that the moisture contained in the Ellerslie soil was considerably below "field capacity" most of the sampling season, and, in many instances, below the "permanent wilting point".

The water available to the soil biomass was determined using the soil moisture retention curve for the Ellerslie soil. The water potentials (ψ) for the Ellerslie soil on the first sampling date are -28.3, -20.3, -27.2, and -26.3 atmospheres for the control, no vegetation, oil and paraffin soils, respectively. Such tensions are greater

TABLE 18. SUMMARY OF THE RESULTS OF THE ELLERSLIE OIL EXPERIMENT

Determinations of gravimetric moisture percentages of four treatments, and their accompanying standard deviations of the mean to a depth of 6 cm. (These represent data collected in 1976).

Date:	26/05/76	31/05/76	7/06/76	15/06/76	30/06/76	9/07/76	16/07/76
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	20.13±0.63	19.91±0.60	20.22±1.27	27.18±5.21	31.92±5.65	31.54±5.62	27.15±5.21
No Veg'n	33.72±4.27	22.50±0.93	19.71±1.30	23.72±4.87	29.86±5.46	30.77±5.55	26.15±5.11
Oil	22.35±0.45	27.53±3.18	26.80±2.67	33.48±5.79	30.22±5.55	33.20±5.77	31.26±5.59
Paraffin	24.90±0.44	24.87±0.43	22.22±1.98	28.85±5.37	33.57±5.79	30.41±5.51	27.95±5.29

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TABLE 19. Gravimetric moisture percentages taken at 3 cm intervals to a depth of 12 cm with accompanying standard deviations of the means.

Date: 3/06/77

Sampling Depth:	0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	44.4±6.7	43.5±6.6	36.9±6.1	40.6±6.4
No Veg'n	38.0±6.2	35.2±5.9	35.2±5.9	39.4±6.3
Oil	49.4±12.0	36.7±6.1	37.7±6.1	36.3±6.0
Paraffin	36.7±6.1	46.7±6.8	37.2±6.1	36.8±6.1

Date: 28/06/77

Sampling Depth:	0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	18.2±4.3	18.4±4.3	18.7±4.3	19.0±4.4
No Veg'n	15.3±3.9	16.8±4.1	18.1±4.2	19.1±4.4
Oil	18.1±4.2	18.9±4.3	18.4±4.3	18.9±4.4
Paraffin	19.2±4.4	18.3±4.3	19.4±4.4	18.7±4.3

Date: 12/08/77

Sampling Depth:	0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	24.6±5.0	26.4±5.1	23.4±4.8	21.7±4.7
No Veg'n	27.6±5.3	25.8±5.1	21.0±4.6	22.3±4.7
Oil	34.4±5.9	31.2±5.6	25.5±5.1	23.4±4.8
Paraffin	26.1±5.1	24.5±5.2	28.7±5.4	25.0±5.0

than those under which moisture-sensitive organisms such as enchytraeids are able to survive. The determination of water activity (Aw) in the Ellerslie soils revealed Aw was in the range of 0.987, thus providing an adequately moisture-laden atmosphere for the soil meiofauna. However, on occasion, this value fell to 0.984 in the "no vegetation: treatment, thus demonstrating a moisture deficit.

B. pH

There is a significant effect of both sampling date and depth on the values of pH determined for the Ellerslie soil (Table 20 and Table 21). Variability in this parameter would be expected with variations in soil moisture as well as the gaseous components of the soil atmosphere observed within the subsequent horizons of the soil profile.

C. SOIL NITROGEN

Ammonium and nitrate nitrogen were determined during the 1976 season (Table 22). Significant variation (p = 0.01) was noted in quantities of NH_4^+ - N and NO_3^- - N in response to depth and sampling date. The "oil" and "paraffin" treatments contained significantly more NH_4^+ - N and NO_3^- - N.

Nitrogen may have been added to the soil along with oil. McGill _et_ _al_., (1980) cited evidence for increased nitrogen fixation in oil-contaminated soils. Gainey (1917), however, gave evidence for the prevention of nitrate accumulation in soils where paraffin was mixed into the soil, or added surficially. Thus, this effect may have been encoun-

TABLE 20. Determinations of pH utilizing a 1:10 ratio of soil to 0.01M $CaCl_2$ to a depth of 6 cm. (Ellerslie, 1976)

Date:	26/05/76	31/05/76	7/06/76	15/06/76	30/06/76	9/07/76	16/07/76
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	5.4±0.2	6.0±0.1	6.0±0.4	5.2±0.2	5.6±0.2	5.7±0.2	5.9±0.2
No Veg'n	5.6±0.1	5.8±0.0	5.6±0.3	5.2±0.2	5.3±0.2	5.7±0.2	5.7±0.2
Oil	5.6±0.1	5.9±0.1	5.6±0.2	5.2±0.2	5.3±0.2	5.6±0.2	5.7±0.2
Paraffin	5.6±0.1	5.8±0.0	5.2±0.3	5.2±0.2	5.4±0.2	5.6±0.0	5.8±0.2

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TABLE 21. pH values as determined with 0.01M $CaCl_2$. Samples were taken at 3 cm intervals to a depth of 12 cm. Standard deviations of the means accompany the results (Ellerslie, 1977).

Date: 28/06/77

Sampling Depth:	0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	5.2±0.2	5.4±0.2	5.6±0.2	5.6±0.2
No Veg'n	5.5±0.2	5.3±0.2	5.3±0.2	5.5±0.2
Oil	5.2±0.2	5.2±0.2	5.4±0.2	5.5±0.2
Paraffin	5.2±0.2	5.3±0.2	5.6±0.2	5.7±0.2

Date: 12/08/77

Sampling Depth:	0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	5.3±0.2	5.3±0.2	5.6±0.2	5.6±0.2
No Veg'n	5.4±0.2	5.4±0.2	5.7±0.2	5.7±0.2
Oil	5.5±0.2	5.6±0.2	5.7±0.2	5.7±0.2
Paraffin	5.5±0.2	5.5±0.2	5.6±0.2	5.8±0.2

TABLE 22. Determinations of mineral nitrogen levels of moist soils as ascertained by steam distillation. The values represent mg of N per g of O.D. soil to a depth of 6 cm (Ellerslie, 1976).

i) Ammonium Nitrogen

Date:	26/05/76	31/05/76	7/06/76	15/06/76	30/06/76	9/07/76	16/07/76
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	7.18± 0.60	1.05±0.42	14.29± 5.80	19.66±4.33	15.43±3.93	27.32±5.23	42.22±6.50
No Veg'n	15.64±17.98	0.43±0.75	21.50±15.85	24.46±4.95	17.04±4.13	29.21±5.40	39.17±6.26
Oil	13.42± 3.28	3.33±1.29	27.15± 1.39	26.53±5.15	22.45±4.74	35.46±5.96	47.34±6.88
Paraffin	10.49± 0.04	1.53±2.06	27.01± 6.11	23.20±4.82	18.69±4.32	36.36±6.03	46.43±6.81

ii) Nitrate Nitrogen

Date:	26/05/76	31/05/76	7/06/76	15/06/76	30/06/76	9/07/76	16/07/76
Treatment:	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	1.69 ± 0.20	4.52±3.03	5.48 ± 2.04	10.79±3.28	5.99±2.45	11.85±3.44	6.77±2.60
No Veg'n	7.79 ± 4.32	1.19±0.89	6.70 ± 4.55	9.64±3.10	7.70±2.78	14.87±3.86	7.41±2.72
Oil	2.40 ± 0.91	3.77±1.76	13.90 ± 3.12	9.93±3.15	15.51±3.94	14.94±3.87	8.97±2.99
Paraffin	1.89 ± 0.25	2.52±1.32	15.22 ± 5.08	9.67±3.11	10.15±3.19	15.49±3.94	7.39±2.72

tered at the soil-paraffin boundary due to immobilization of nitrogen. However, the application of paraffin to the soil surface resulted in slightly elevated moisture levels. This may have induced microbial activity with subsequent increases in mineralization in an environment which apparently has a moisture deficit.

The ammonium:nitrate ratios exceeded 1, which is commonly noted in many grassland soils (Soulides and Clark, 1958; Moore and Waid, 1971). The amounts of both NH_4^+ - N and NO_3^- - N increase during the year and tend to stay reasonably high relative to data reported for other grasslands (Woldendorp _et_ _al_., 1966). This may be a result of a moisture deficit and a subsequent reduction in plant growth, along with recycling of litter in unharvested sites.

D. SOIL TEMPERATURE

The soil temperature differed significantly with the sampling date (p=0.01) and treatment (p=0.01) during both sampling seasons (Table 23 and 24). Temperature was measured at depth in the 1977 sampling season only, and was found to vary significantly with the depth in the profile (p=0.01). The oiled soil was significantly cooler than the control soil in both sampling seasons. This may have been due to an elevated moisture level in this soil. The vegetation present upon addition of the oil was killed, but not removed. However, a new crop of grass soon developed on these plots, thus the albedo was not reduced.

TABLE 23. Temperature readings taken at two/three intervals (3-6 cm) during the day. Temperature was taken in centigrade degrees (Ellerslie, 1976).

Date:		26/05/76		31/05/76		7/06/76		15/06/76	
Treatment:		$\bar{x}$	T_A*	$\bar{x}\pm$S.D.	T_A	$\bar{x}\pm$S.D.	T_A	$\bar{x}\pm$S.D.	T_A
Control	1000 hr.	14.9		12.5±0.4	15.7	14.0±0.1	23		20.2
	1200 hr.	13.9		12.4±0.5	17.1	17.1±1.0	20	16.7±4.1	
	1400 hr.	13.5		13.5±0.6	16.8				
No Veg'n	1000 hr.	14.8		12.9±0.2					
	1200 hr.	13.5		12.8±0.6		15.7±0.5		17.2±0.3	
	1400 hr.	13.0		14.1±0.1		19.1±1.3			
Oil	1000 hr.	14.5		12.0±0.1					
	1200 hr.	14.0		12.1±0.1		13.0±0.1		12.6±3.6	
	1400 hr.	13.1		13.0±0.1		15.9±0.8			
Paraffin	1000 hr.	14.9		12.8±0.3		14.5±0.6		15.9±4.0	
	1200 hr.	13.6		12.5±0.4		17.1±0.7			
	1400 hr.	13.1		13.2±0.2					

Date:		30/06/76		9/07/76		13/08/76		10/09/76		20/09/76	
Treatment:		$\bar{x}\pm$S.D.	T_A	$\bar{x}\pm$S.D.	T_A	$\bar{x}\pm$S.D.	T_A	$\bar{x}\pm$S.D.	T_A	$\bar{x}\pm$S.D.	T_A
Control	1000 hr.	17.2±4.2	27	19.7±4.4	26	20.6±4.5	23	12.7±3.6	17	13.1±3.6	20
	1200 hr.	18.7±4.3	24	21.7±4.7	22	22.5±4.8	23.8				
	1400 hr.	19.0±4.4	25	22.6±4.8	27.5	24.5±5.0	28.2	14.6±3.8	15	16.2±4.0	27
No Veg'n	1000 hr.	18.4±4.3		20.0±4.5		21.4±4.6		12.0±3.5		13.2±3.6	
	1200 hr.	19.4±4.4		22.6±4.8		23.5±4.9					
	1400 hr.	20.2±4.5		23.8±4.9		24.6±5.0		14.1±3.8		16.1±4.0	
Oil	1000 hr.	17.0±4.1		18.6±4.3		20.9±4.6		12.5±3.5		13.2±3.6	
	1200 hr.	18.1±4.3		21.0±4.6		22.3±4.7					
	1400 hr.	18.3±4.3		21.5±4.6		23.9±4.9		14.4±3.8		14.8±3.9	
Paraffin	1000 hr.	18.0±0.0		19.8±4.4		20.9±4.6		12.6±3.6		13.2±3.6	
	1200 hr.	18.4±4.3		22.3±4.7		22.7±4.8					
	1400 hr.	18.9±4.3		22.9±4.8		24.1±4.9		14.2±3.8		15.3±3.9	

*T_A = Air Temperature

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TABLE 24. Temperature readings taken at 3 cm intervals (Ellerslie, 1977)

Date:		3/06/77			
Depth:		0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:		$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	1000 hr.	14.8±3.8	14.8±3.9	13.7±3.7	
	1200 hr.	12.6±3.5	11.1±3.3	10.7±3.3	
	1400 hr.	14.5±3.8	13.3±3.6	12.2±3.5	
No Veg'n	1000 hr.	13.4±4.2	16.1±4.0	15.3±3.9	
	1200 hr.	14.0±3.7	12.5±3.5	11.7±3.2	
	1400 hr.	16.7±4.1	14.9±3.9	14.3±3.8	
Oil	1000 hr.	15.0±3.9	13.8±3.7	12.8±3.6	
	1200 hr.	12.6±3.5	11.6±3.4	10.9±3.3	
	1400 hr.	14.4±3.8	13.3±3.6	12.3±3.5	
Paraffin	1000 hr.	16.1±4.0	14.2±3.8	13.3±6.3	
	1200 hr.	12.2±3.5	11.9±3.5	11.1±3.3	
	1400 hr.	16.1±4.0	15.1±3.9	13.1±3.6	
	T_A*:	1000 hr. 33°C	1200 hr. 19.2°C	1400 hr. 24°C	

Date:		28/06/77			
Depth:		0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:		$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	1000 hr.				
	1200 hr.	21.2±4.6	18.7±4.3	17.7±4.2	
	1400 hr.				
No Veg'n	1000 hr.				
	1200 hr.	23.0±4.8	19.8±4.5	17.8±4.2	
	1400 hr.				
Oil	1000 hr.				
	1200 hr.	18.9±4.3	16.9±4.1	16.2±4.0	
	1400 hr.				
Paraffin	1000 hr.				
	1200 hr.	21.6±4.6	19.2±4.4	17.9±4.2	
	1400 hr.				
	T_A:	1200 hr. 24°C			

Date:		12/08/77			
Depth:		0-3 cm.	3-6 cm.	6-9 cm.	9-12 cm.
Treatment:		$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control	1000 hr.				
	1200 hr.	15.8±4.0	15.2±3.9	15.3±3.9	14.8±3.8
	1400 hr.	16.8±4.1	16.0±4.0	15.9±3.9	15.0±3.9
No Veg'n	1000 hr.				
	1200 hr.	16.6±4.1	16.1±4.0	15.9±4.0	15.6±4.0
	1400 hr.	18.0±4.2	17.1±4.1	16.4±4.1	16.0±4.0
Oil	1000 hr.				
	1200 hr.	16.0±4.0	15.4±3.9	14.9±3.9	14.7±3.8
	1400 hr.	16.5±4.1	15.7±4.0	15.2±3.9	15.0±3.9
Paraffin	1000 hr.				
	1200 hr.	16.2±4.0	15.6±4.0	15.2±3.9	15.0±3.9
	1400 hr.	17.1±4.1	16.0±4.0	15.5±3.9	15.1±3.9
	T_A:	1200 hr 21°C	1400 hr. 21.8°C		

*T_A = Air Temperature

E. THE SOIL MICROATHROPODS

Analysis of variance in the first sampling season was undertaken to determine the effect of treatment and sampling date on the Collembola and mites. The number of both Collembola and mites varied significantly ($p = 0.05$) with sampling date over the first sampling season (Table 25). No significant effect due to treatment was noted. In addition, no significant effect was noted in a direct comparison of the control and "oil" soil (Table 26) and the control and "no vegetation" treatment (Table 27) using a T-test.

Factorial analysis of variance incorporated using the data from the 1977 sampling season (Table 28) revealed a differential effect on the Collembola and mites. For example, the Collembola were found to vary significantly with the sampling date ($p = 0.05$). The mites, however, varied significantly with the depth in the horizon ($p = 0.01$). No effect was noted due to treatment during the 1977 sampling season.

The number of Collembola and mites varied coincidently with changes in soil moisture. For example, the drier surface soil horizons experienced in the 28/06/77 sample (Table 19) was coincident with a drop in the numbers of Collembola and mites at this soil depth.

TABLE 25. Enumeration of soil microarthropods on two sampling dates for the 1976 sampling season. Note that due to lack of space on the Macfadyen high gradient extractor, the number of samples were limited. Two treatments were chosen for so-called depth-sampling (samples taken at 3 cm intervals to a total depth of 12 cm.); all other samples were taken at a depth of 3-6 cm. The standard deviation of the mean, as well as the number of samples taken (n) are also indicated.

Date:		15/06/76		13/08/76	
		#COLLEMBOLS m^{-2}	#MITES m^{-2}	#COLLEMBOLS m^{-2}	#MITES m^{-2}
Treatment		$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.	$\bar{x}$±S.D.
Control n=4	(3-6 cm)	6x10^{4}±2.5x10^{2}	6x10^{4}±2.5x10^{2}	6x10^{5}±8x10^{2}	4x10^{6}±2x10^{3}
Control	(0-3 cm)	6x10^{3}	3x10^{5}	8x10^{5}	8x10^{5}
	(3-6 cm)	9x10^{4}	5x10^{4}	8x10^{5}	4x10^{6}
n=1	(6-9 cm)	4x10^{4}	1x10^{5}	5x10^{5}	2x10^{6}
	(9-12 cm)	8x10^{4}	4x10^{4}	1x10^{5}	2x10^{5}
No Veg'n n=4	(3-6 cm)	5x10^{4}± 2x10^{2}	4x10^{4}± 2x10^{2}	10x10^{5}± 10x10^{2}	1x10^{6}± 1x10^{3}
No Veg'n	(0-3 cm)	4x10^{4}	3x10^{4}		
	(3-6 cm)	7x10^{4}	7x10^{4}		
n=1	(6-9 cm)	4x10^{4}	9x10^{3}		
	(9-12 cm)				
Oil	(3-6 cm)	3x10^{5}±5x10^{2}	3x10^{5}±2x10^{3}	n=3 4x10^{5}±6x10^{2}	4x10^{6}±2x10^{3}
Paraffin n=4	(3-6 cm)	6x10^{4}±2x10^{2}	5x10^{5}±7x10^{2}	6x10^{5}±8x10^{2}	3x10^{6}±2x10^{3}

Analysis of variance indicates significant variation due to sampling date.

TABLE 26. A comparison of the number of soil microarthropods found within the control soil, and those found in that treated with oil. Samples were taken in 3 cm intervals to a depth of 9 cm. Standard deviation of the mean as well as the number of samples taken (n) are indicated.

Date: 30/07/76

		n	#COLLEMBOLS m^{-2} $\bar{x}\pm$S.D.	n	#MITES m^{-2} $\bar{x}\pm$S.D.
Control	(0-3 cm)	3	$4\times10^{5}\pm7\times10^{2}$	3	$8\times10^{5}\pm9\times10^{2}$
	(3-6 cm)	3	$3\times10^{5}\pm5\times10^{2}$	3	$9\times10^{5}\pm1\times10^{3}$
	(6-9 cm)	3	$1\times10^{5}\pm3\times10^{2}$	3	$7\times10^{5}\pm9\times10^{2}$
Oil	(0-3 cm)	4	$4\times10^{5}\pm6\times10^{2}$	4	$6\times10^{5}\pm8\times10^{2}$
	(3-6 cm)	4	$1\times10^{5}\pm4\times10^{2}$	4	$8\times10^{5}\pm9\times10^{2}$
	(6-9 cm)	4	$2\times10^{5}\pm5\times10^{2}$	4	$2\times10^{6}\pm1\times10^{3}$

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TABLE 27. Enumeration of soil microarthropods for 26/04/77. Sampling was done on this occasion as it was carried out in 1976. The majority of samples were taken to a 3-6 cm. depth. Two treatments were chosen to be sampled at depth.

Date:			26/04/77	
			#COLLEMBOLS m^{-2}	#MITES m^{-2}
		n	$\bar{x}\pm$S.D.	$\bar{x}\pm$S.D.
Control	(3-6 cm)	4	$8\times10^{5}\pm9\times10^{2}$	$2\times10^{6}\pm4\times10^{1}$
Control	(0-3 cm)	1	2×10^{5}	3×10^{6}
	(3-6 cm)	1	3×10^{6}	6×10^{6}
	(6-9 cm)	1	4×10^{4}	5×10^{6}
	(9-12 cm)	1	7×10^{3}	5×10^{5}
No Veg'n	(3-6 cm)	4	$1\times10^{5}\pm4\times10^{2}$	$2\times10^{6}\pm1\times10^{3}$
No Veg'n	(0-3 cm)	1	2×10^{5}	3×10^{6}
	(3-6 cm)	1	4×10^{5}	2×10^{6}
	(6-9 cm)	1	7×10^{4}	5×10^{5}
	(9-12 cm)	1	8×10^{4}	2×10^{6}
Oil	(3-6 cm)	4	$1\times10^{5}\pm3\times10^{2}$	$4\times10^{5}\pm6\times10^{2}$
Paraffin	(3-6 cm)	4	2×10^{5}	5×10^{5}

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TABLE 28. Enumeration of soil microarthropods for three sampling dates during the 1977 season. Samples were taken at 3 cm. intervals to a total depth of 12 cm. for all replicates. N=4 for all samples.

Date:		3/06/77		30/06/77		12/08/77	
		#COLLEMBOLS m^{-2} $\bar{x}\pm$S.D.	#MITES m^{-2} $\bar{x}\pm$S.D.	#COLLEMBOLS m^{-2} $\bar{x}\pm$S.D.	#MITES m^{-2} $\bar{x}\pm$S.D.	#COLLEMBOLS m^{-2} $\bar{x}\pm$S.D.	#MITES m^{-2} $\bar{x}\pm$S.D.
Control	(0-3 cm)	$5x10^5\pm7x10^2$	$2x10^6\pm1x10^3$	$3x10^4\pm2x10^2$	$10x10^5\pm1x10^3$	$3x10^5\pm5x10^2$	$3x10^6\pm2x10^3$
	(3-6 cm)	$1x10^5\pm4x10^2$	$5x10^5\pm7x10^2$	$1x10^5\pm3x10^2$	$8x10^5\pm9x10^2$	$2x10^5\pm4x10^2$	$1x10^6\pm1x10^3$
	(6-9 cm)	$6x10^4\pm3x10^2$	$5x10^5\pm7x10^2$	$1x10^5\pm3x10^2$	$6x10^5\pm8x10^2$	$1x10^6\pm1x10^3$	$5x10^5\pm7x10^2$
	(9-12 cm)	$8x10^4\pm3x10^2$	$7x10^5\pm9x10^2$	$1x10^5\pm3x10^2$	$9x10^5\pm1x10^3$	$5x10^5\pm7x10^2$	$5x10^5\pm7x10^2$
No Veg/n	(0-3 cm)	$1x10^5\pm4x10^2$	$1x10^6\pm1x10^3$	$3x10^4\pm2x10^2$	$1x10^6\pm1x10^3$	$2x10^5\pm4x10^2$	$1x10^6\pm1x10^3$
	(3-6 cm)	$6x10^4\pm2x10^2$	$4x10^5\pm6x10^2$	$8x10^4\pm3x10^2$	$7x10^5\pm9x10^2$	$1x10^5\pm3x10^2$	$8x10^5\pm9x10^2$
	(6-9 cm)	$2x10^5\pm4x10^2$	$6x10^5\pm8x10^2$	$1x10^5\pm4x10^2$	$9x10^5\pm1x10^3$	$2x10^5\pm5x10^2$	$1x10^6\pm1x10^3$
	(9-12 cm)	$7x10^4\pm3x10^2$	$6x10^5\pm8x10^2$	$2x10^5\pm4x10^2$	$7x10^5\pm8x10^2$	$9x10^5\pm9x10^2$	$1x10^6\pm1x10^3$
Oil	(0-3 cm)	$1x10^5\pm4x10^2$	$1x10^6\pm1x10^3$	$5x10^4\pm2x10^2$	$3x10^5\pm6x10^2$	$1x10^5\pm3x10^2$	$4x10^5\pm6x10^2$
	(3-6 cm)	$4x10^2\pm2x10^2$	$5x10^5\pm7x10^2$	$1x10^5\pm4x10^2$	$4x10^5\pm6x10^2$	$2x10^5\pm4x10^2$	$7x10^5\pm8x10^2$
	(6-9 cm)	$5x10^4\pm2x10^2$	$7x10^5\pm8x10^2$	$1x10^5\pm3x10^2$	$6x10^5\pm8x10^2$	$1x10^5\pm4x10^2$	$5x10^5\pm7x10^2$
	(9-12 cm)	$7x10^5\pm2x10^2$	$4x10^5\pm6x10^2$	$1x10^5\pm3x10^2$	$7x10^5\pm8x10^2$	$9x10^4\pm3x10^2$	$6x10^5\pm8x10^2$
Paraffin	(0-3 cm)	$1x10^5\pm4x10^2$	$6x10^5\pm8x10^2$	$3x10^4\pm2x10^2$	$3x10^5\pm6x10^2$	$2x10^5\pm4x10^2$	$1x10^6\pm1x10^3$
	(3-6 cm)	$5x10^4\pm2x10^2$	$6x10^5\pm8x10^2$	$5x10^4\pm2x10^2$	$5x10^5\pm7x10^2$	$1x10^5\pm3x10^2$	$4x10^5\pm6x10^2$
	(6-9 cm)	$6x10^4\pm3x10^2$	$6x10^5\pm8x10^2$	$9x10^4\pm3x10^2$	$6x10^5\pm8x10^2$	$7x10^4\pm3x10^2$	$3x10^5\pm5x10^2$
	(9-12 cm)	$8x10^4\pm3x10^2$	$7x10^5\pm8x10^2$	$9x10^4\pm3x10^2$	$7x10^5\pm8x10^2$	$1x10^5\pm3x10^2$	$5x10^5\pm7x10^2$

DISCUSSION

The Ellerslie soil was dry on most sampling occasions, thus organisms living in this environment live under conditions of a moisture deficit. The single application of oil altered some of the characteristics of this environment: the moisture levels and NH_4^+ and NO_3^- concentrations of the oil and paraffin soils were considerably higher than the control soil, and the temperature of the oil soil was considerably lower. Thus, any detrimental effect due to oil, such as its toxicity, may have been overcome by a habitat more conducive for existence in these soils. The toxicity of the oil could not have been long-lasting, for at no time did the applied treatments significantly alter the population of Collembola and mites.

The conditions of this experiment do not simulate those found in the vicinity of a heavy oil spill, however, they do demonstrate the ability of the meiofauna to exist and maintain their population in the presence of low levels of oil, as may be found at the edge of an oil spill. This study does indicate that small oil additions do not act as a permanent sterilant, and that alterations in the soil character may actually be improved for the soil biomass under low levels of addition of oil.

These data do not imply that soil microarthropods are immune but rather that the system is robust against some of these effects. A number of mechanisms may be used by these organisms to escape the presence of oil. For example, the soil microarthropods are mobile, and may escape the approaching front of oil by a downward migration. Larger soil pores may provide areas of refuge from the oil and adsorption onto soil organic matter and litter may also reduce its accessibility to the meiofauna. The microarthropods which are initially killed by the volatile components of the oil, may be replaced by organisms migrating inward from the surrounding buffer regions, once the toxic components of the oil have been dissipated or decomposed by soil microbes. An example of an initial lethal effect of diesel fuel followed by recovery of nematode and harpacticoides populations has been provided by Wormald (1976). Following contamination of a sandy beach with diesel oil, nematodes and harpacticoides were initially completely eliminated. After one year meiofauna populations returned to normal and after 15-16 months more nematodes and harpacticoides were present in the contaminated than in adjacent control areas. In comparing these data with the present study it should be remembered that diesel fuel is more volatile and toxic than is crude oil and that sands are much less capable of buffering against effects of oil than are more organic or heavier textured soils (McGill et al, 1980). The toxic characteristics of oil on organisms if the two come into direct contact cannot be denied. However, these data suggest that at low rates of oil addition to soil, many microsites may in fact not contain free oil capable of coming in contact with soil meiofauna. Further volatilization and adsorption and microbial decomposition in organic-rich soils may quickly remove the most directly toxic components of crude oil thus preventing their future contact with meiofauna. Further research is needed to explain mechanisms preventing meiofauna-oil contact in lightly contaminated soil and also in facilitating meiofaunal reinvasion of previously contaminated areas.

SUMMARY

The soil microflora and meiofauna contribute to the character of the soil organic matter through their biomass, as well as their ability to recycle immobilized nutrients. In particular, the comminution of litter by the meiofauna increases the surface area of organic debris. In addition to this function, translocation and grazing of the microbial flora by Collembola and mites stimulates and distributes the microbial mineralization of organic constituents (Wiggin and Curl, 1979). Thus the microflora and meiofauna work in conjunction to release immobilized nutrients, and it is this function that demonstrates their importance.

Numerous studies on the taxonomic characterization of the soil meiofauna do not lead to any general conclusion in terms of interspecific relationships. These relationships, may differ from one soil to the next. Reichle (1971) states that the functioning of ecological systems is best understood in terms of trophic relationships, for they transcend taxonomic differences. The omission of one taxonomic group from a soil population does not result in a curtailed mineralization process, the omitted organism is replaced by one with similar trophic requirements. It is the nature of the soil environment which necessitates the adaptability of the soil organism to a variety of environmental conditions as well as substrate. For example, during litter deposition, the meiofauna has an adequate supply of organic detritus. This may be depleted, thus, forcing the meiofauna to exploit the microflora.

The soil biomass experiences spatial as well as temporal variability in soil characters such as moisture, temperature, pH, as well as substrate concentration. These characteristics not only vary from one soil or horizon to another, but, also on a micro-scale. The techniques used to quantify these parameters, are however, not sensitive enough to measure minute alterations which may be encountered in these microsites.

The soil is an environment which is comparatively nutrient-limited, and highly competitive. When extracted, the soil solution could adequately provide substrate for an estimated 40-84% of the maximum growth rate expected of the microbial population under optimal conditions. However, a number of other factors must be considered in the soil environment, for example, diffusion is slowed in soil by adsorption which may act to reduce the availability of substrate to microsites. The physical accessibility of the substrate must also be considered. For example, substrates bound within the complex humic substances are available for utilization, and may be released into solution at a rate determined by the rate of decomposition of the more complex molecules. These adsorption processes are also inherent in clay minerals. Accessibility of organics appears to be a factor in controlling lethal effects of oil on soil as well as on organic matter decomposition.

Thus, it is important to consider the system as a whole, for the interaction of biomass and the physico-chemical make-up of a soil is an intimate one. The chemical milieu of a soil is determined by the parent material which forms the structural framework of that soil. In turn, the soil organisms inhabiting that soil are adapted to particular environmental conditions, and consequently contribute to mineralization processes and production of structural componets of the soil. Thus organisms are in turn affected by the environment they help create.

This study attempted to examine portions of both the living and inanimate components of the soil environment. A study of the water-soluble organic matter of the soil, as well as the measurement of the bacterial and meiofaunal population enabled a correlation of the substrate level of three soils to the soil organism. The soil bacteria and Collembola and mites were found to follow the general trend set by readily utilizable carbon and soil moisture contents.

A study of the effect of oil and simulated conditions of a spill (surface crusting and removal of vegetation) revealed no significant effect of treatment upon the soil Collembola and mites. However, the soil moisture, NH_4^+ and NO_3^- concentration of the soil, as well as soil temperature varied significantly with treatment and sampling date.

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APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

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1. Gravimetric percentage moistures determined to a 6 cm depth.

Date:		31/05	7/06	15/06	30/06	9/07	16/07
Treatment	Rep.						
Control	1	20.2	20.9	26.9	35.0	32.5	30.6
	2	19.2	18.3	28.7	29.8	31.8	27.2
	3	20.3	20.6	24.2	31.0	31.6	24.3
	4	20.4	21.1	28.9	31.9	30.3	26.4
No Veg.	1	23.0	20.7	23.8	29.5	31.1	28.1
	2	22.5	20.2	23.5	30.6	32.8	23.5
	3	23.3	20.2	24.8	30.2	30.6	26.6
	4	21.1	17.8	22.9	29.1	28.7	26.4
Oil	1	28.8	26.3	35.2	28.5	32.5	32.5
	2	29.3	24.4	27.5	30.9	31.4	29.6
	3	29.2	26.0	34.8	27.4	35.0	33.2
	4	22.8	30.6	36.4	34.2	34.0	29.8
Para.	1	25.5	25.1	29.7	33.7	28.9	28.8
	2	24.8	21.4	26.6	31.2	31.9	27.3
	3	24.7	20.6	31.3	34.3	31.9	29.3
	4	24.5	21.8	27.8	35.0	28.9	26.4

APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

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2. Soil pH determined in 0.01 M $CaCl_2$ to a 6 cm depth.

Date:		31/05	7/06	15/06	30/06	9/07	16/07
Treatment	**Rep.**						
Control	1	6.0	6.4	5.2	6.2	5.6	6.0
	2	6.0	6.2	5.3	5.6	5.7	5.8
	3	6.0	5.7	5.0	5.5	5.7	5.8
	4	5.9	5.5	5.2	5.2	5.6	5.8
No Veg.	1	5.8	5.8	5.4	5.3	5.7	5.6
	2	5.8	5.7	5.3	5.4	5.8	5.7
	3	5.8	5.3	5.3	5.3	5.7	5.7
	4	5.8	5.4	4.9	5.2	5.6	5.8
Oil	1	5.9	5.3	5.3	5.1	5.6	5.5
	2	5.9	5.7	5.2	5.3	5.7	5.7
	3	5.8	5.7	5.2	5.3	5.6	5.8
	4	5.8	5.6	4.9	5.4	5.6	5.6
Para.	1	5.8	4.7	5.4	5.4	5.6	5.8
	2	5.8	5.2	5.2	5.2	5.6	5.8
	3	5.8	5.4	5.3	5.2	5.6	5.8
	4	5.8	5.3	4.8	5.4	5.6	5.6

APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

3. Soil temperature at the Ellerslie soil read at a 6 cm depth at 1200 hr.

Date:		31/05	7/06	15/06	30/06	19/07	13/08
Treatment	**Rep.**						
Control	1	12.0	16.0	16.2	19.1	20.5	23.0
	2	13.0	16.5	17.0	18.0	22.1	22.0
	3	12.6	18.0	16.0	18.6	22.2	22.1
	4	12.0	18.0	17.5	19.0	22.1	23.0
No Veg.	1	11.9	17.2	17.0	19.1	21.9	23.0
	2	13.1	19.1	17.5	19.1	22.6	23.0
	3	13.0	19.9	16.9	19.7	24.0	23.9
	4	13.0	20.0	17.5	19.5	22.0	24.0
Oil	1	12.0	15.2	15.8	18.2	21.0	22.0
	2	12.1	15.5	15.1	18.2	21.1	22.9
	3	12.0	17.0	15.6	18.0	21.0	22.2
	4	12.0	16.0	14.5	18.0	21.1	22.2
Para.	1	13.0	17.0	16.6	18.5	22.2	23.0
	2	12.3	16.2	16.1	19.0	22.8	22.2
	3	12.1	17.1	16.0	18.0	22.1	22.5
	4	12.5	18.0	15.0	18.0	22.1	23.0

APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

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4. The NH_4-N (ug NH_4-N/g O.D. soil) content of the Ellerslie soil determined to a 6 cm depth.

Date:		31/05	7/06	15/06	30/06	9/07	16/07
Treatment	Rep.						
Control	1	1.68	19.87	19.10	12.28	12.05	39.75
	2	0.83	18.64	16.67	17.25	26.75	43.64
	3	0.84	10.14	18.70	19.70	28.55	40.44
	4	0.84	8.48	24.81	12.47	41.93	42.04
No Veg.	1	--	42.64	26.86	24.48	30.28	41.23
	2	1.29	19.35	27.22	12.34	31.61	40.62
	3	--	4.21	20.95	17.77	31.07	38.10
	4	--	19.79	22.79	13.55	23.87	36.73
Oil	1	4.51	27.40	29.80	25.64	25.03	49.14
	2	2.71	27.86	23.63	14.18	35.41	43.52
	3	1.81	28.21	27.36	23.19	36.84	52.20
	4	4.29	25.13	25.31	26.78	44.57	44.49
Para.	1	1.76	35.48	19.52	17.31	39.24	45.95
	2	--	27.18	23.48	19.75	31.40	45.87
	3	4.36	21.51	22.51	19.26	36.02	42.56
	4	--	23.87	27.26	18.42	38.79	51.33

APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

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5. The NO_3-N content (ug NO_3-N/g O.D. soil) of the Ellerslie soil determined to a depth of 6 cm.

Date:		31/05	7/06	15/06	30/06	9/07	16/07
Treatment	Rep.						
	1	6.02	4.23	12.88	4.72	8.34	5.48
	2	6.26	3.31	10.36	4.54	16.14	7.57
	3	6.32	6.76	10.44	10.08	12.89	6.96
	4	5.48	7.63	9.47	4.62	10.03	7.08
No Veg.	1	2.15	10.13	13.43	9.97	15.60	8.52
	2	1.29	8.41	8.64	6.40	14.87	5.19
	3	1.30	8.93	9.60	9.15	11.88	7.09
	4	1.58	8.25	6.88	8.50	17.12	8.85
Oil	1	1.35	15.91	23.18	21.59	12.98	12.05
	2	4.07	9.58	1.34	8.24	12.88	8.16
	3	4.07	13.67	7.55	12.04	18.89	8.39
	4	5.58	16.45	7.64	20.20	15.01	7.26
Para.	1	4.39	21.46	6.36	13.10	18.94	5.41
	2	2,19	9.77	6.20	11.48	13.39	8.91
	3	2.18	16.87	6.43	9.40	13.39	7.25
	4	1.31	12.79	19.67	6.61	16.24	7.27

APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

6. Enumeration of Arthropods in the Ellerslie soil determined at the 3-6 cm depth.

Date: 15/06/76

Treatment	Rep.		#Collembola m^{-2} (x 10^4)	#Mites m^{-2} (x 10^4)
Control	1	(3-6 cm)	7.1	6.3
	2	(3-6 cm)	4.8	3.4
	3	(3-6 cm)	4.6	10.0
	4	(3-6 cm)	8.8	5.3
No Veg.	1	(3-6 cm)	5.7	1.2
	2	(3-6 cm)	3.7	1.6
	3	(3-6 cm)	7.3	7.3
	4	(3-6 cm)	4.0	280.0
Oil	1	(3-6 cm)	1.1	48.0
	2	(3-6 cm)	1.7	9.8
	3	(3-6 cm)	7.9	93.0
	4	(3-6 cm)	2.2	31.0
Para.	1	(3-6 cm)	0.4	5.0
	2	(3-6 cm)	14.0	10.0
	3	(3-6 cm)	25.0	15.0
	4	(3-6 cm)	18.0	5.3

Date: 13/08/76

			#Collembola m^{-2} (x 10^5)	#Mites m^{-2} (x 10^6)
Control	1	(3-6 cm)	5.7	5.7
	2	(3-6 cm)	6.8	2.7
	3	(3-6 cm)	43.0	3.5
	4	(3-6 cm)	33.0	4.3
No Veg.	1	(3-6 cm)	23.0	2.3
	2	(3-6 cm)	93.0	0.9
	3	(3-6 cm)	36.0	6.3
	4	(3-6 cm)	3.9	0.4
Oil	1	(3-6 cm)	38.0	3.8
	2	(3-6 cm)	36.0	3.6
	3	(3-6 cm)	40.0	4.0
	4	(3-6 cm)	30.0	3.0
Para.	1	(3-6 cm)	25.0	25.0
	2	(3-6 cm)	10.0	1.1
	3	(3-6 cm)	49.0	4.9
	4	(3-6 cm)	44.0	4.4

APPENDIX A. ELLERSLIE OIL EXPERIMENT, 1976

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7. Arthropod Enumeration: Comparison of control vs. oil treatment at depth. (Raw Data)

Date: 30/06/76

Treatment	Rep.		#Collembola m^{-2}	#Mites m^{-2}
Control	1	(0-3 cm)	5.9×10^5	7.4×10^5
	2	(0-3 cm)	6.1×10^5	1.6×10^6
	3	(0-3 cm)	1.2×10^5	1.3×10^5
Control	1	(3-6 cm)	3.0×10^5	7.6×10^4
	2	(3-6 cm)	2.3×10^5	1.8×10^6
	3	(3-6 cm)	2.7×10^5	1.9×10^6
Control	1	(6-9 cm)	1.3×10^5	1.8×10^5
	2	(6-9 cm)	8.0×10^5	1.3×10^6
	3	(6-9 cm)	4.7×10^5	1.5×10^6
Oil	1	(0-3 cm)	3.7×10^5	2.9×10^5
	2	(0-3 cm)	3.4×10^5	8.9×10^4
	3	(0-3 cm)	3.5×10^5	3.8×10^5
Oil	1	(3-6 cm)	8.7×10^4	3.7×10^5
	2	(3-6 cm)	8.3×10^4	1.4×10^6
	3	(3-6 xm)	1.6×10^5	1.4×10^6
Oil	1	(6-9 cm)	2.7×10^5	9.9×10^5
	2	(6-9 cm)	1.9×10^5	3.7×10^6
	3	(6-9 cm)	3.4×10^5	2.3×10^6

APPENDIX B. ELLERSLIE OIL EXPERIMENT, 1977

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8. The gravimetric moisture percentage determined at 3 cm intervals to a depth of 12 cm.

Date:			3/06/77		
Depth:		0-3 cm	3-6 cm	6-9 cm	9-12 cm
Treatment	**Rep.**				
Control	1	39.78	35.63	37.42	37.80
	2	44.74	35.99	37.24	35.22
	3	50.17	34.78	37.59	37.17
	4	42.90	67.44	35.55	30.73
No Veg.	1	41.19	35.28	36.15	35.43
	2	35.37	35.47	35.68	36.30
	3	38.66	34.23	35.02	34.34
	4	36.68	35.84	33.78	50.51
Oil	1	46.58	37.18	37.41	35.97
	2	37.50	34.77	36.08	35.44
	3	47.49	37.94	38.08	37.18
	4	65.98	36.82	39.27	36.56
Para.	1	36.77	36.34	36.12	35.97
	2	41.87	52.32	38.48	36.21
	3	24.11	35.18	37.13	37.19
Date:			30/06/77		
Control	1	17.13	17.40	17.63	17.36
	2	15.65	16.44	16.79	16.65
	3	19.90	19.59	20.06	21.00
	4	20.01	20.20	20.34	20.74
No Veg.	1	18.60	17.38	17.26	17.55
	2	13.36	16.08	18.08	18.70
	3	14.63	17.97	19.05	20.49
	4	14.44	15.76	17.71	19.96
Oil	1	14.77	15.88	15.95	16.97
	2	12.48	21.39	17.96	18.74
	3	24.59	[illegible].97	21.46	20.82
	4	20.31	17.21	18.18	19.07
Para.	1	16.40	16.88	17.64	18.37
	2	24.56	18.56	21.85	18.73
	3	17.93	19.17	19.78	19.53
	4	17.87	18.51	18.03	18.19
Date:			12/08/77		
Control	1	28.49	24.30	11.32	21.40
	2	35.00	24.32	28.45	17.80
	3	30.71	28.01	26.59	22.88
	4	34.29	29.17	27.23	25.43
No Veg.	1	29.72	26.51	23.40	19.99
	2	33.34	28.95	25.14	23.35
	3	23.75	21.97	20.28	17.33
	4	23.55	25.71	15.10	28.36
Oil	1	34.63	30.59	28.46	27.05
	2	32.06	32.55	30.03	28.11
	3	33.53	--	12.20	14.50
	4	37.46	30.53	31.08	23.78
Para.	1	35.75	33.97	29.26	26.87
	2	34.82	29.63	28.11	28.55
	3	8.06	23.61	33.61	22.37
	4	25.73	22.72	23.55	22.22

9. The pH (0.01 M $CaCl_2$) in the Ellerslie soil determined to a 12 cm depth at 3 cm.

Date:			28/06/77		
Depth:		0-3 cm	3-6 cm	6-9 cm	9-12 cm
Treatment	**Rep.**				
Control	1	5.8	5.7	6.0	5.8
	2	5.4	5.6	5.8	5.7
	3	5.0	5.1	5.4	5.5
	4	5.0	5.1	5.2	5.3
No Veg.	1	5.5	5.5	5.6	5.7
	2	5.4	5.5	5.7	5.7
	3	5.1	5.0	5.0	5.3
	4	5.9	5.1	5.0	5.2
Oil	1	5.4	5.3	5.6	5.7
	2	5.2	5.3	5.7	5.8
	3	5.1	5.3	5.2	5.2
	4	4.9	5.0	5.2	5.3
Para.	1	5.2	5.6	5.4	5.4
	2	5.4	5.5	6.0	5.8
	3	5.0	5.0	5.2	5.6
	4	5.2	5.1	5.2	5.4
Date:			12/08/77		
Control	1	4.4	5.4	5.5	5.6
	2	5.5	5.3	5.5	5.7
	3	5.7	5.6	5.7	5.5
	4	5.4	5.4	5.5	5.6
No Veg.	1	5.1	5.1	5.5	5.4
	2	5.4	5.4	5.8	5.9
	3	5.7	5.7	5.7	5.7
	4	5.5	5.5	5.5	5.6
Oil	1	5.4	5.4	5.4	5.6
	2	5.5	5.6	5.7	5.8
	3	5.5	5.7	5.8	5.8
	4	5.5	5.5	6.0	5.7
Para.	1	5.3	5.3	5.4	5.8
	2	5.5	5.6	5.8	5.7
	3	5.7	5.7	5.7	5.9
	4	5.5	5.4	5.4	5.6

APPENDIX B. ELLERSLIE OIL EXPERIMENT, 1977

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10. The mid-day temperature readings of the Ellerslie soil read at 3 cm intervals to a depth of 12 cm.

Date:		3/06/77			
Depth:		0-3 cm	3-6 cm	6-9 cm	9-12 cm
Treatment	Rep.				
Control	1	12.8	11.2	10.8	—
	2	12.0	10.5	10.1	—
	3	12.5	11.4	10.9	—
	4	12.9	11.1	10.9	—
No Veg.	1	13.2	11.9	11.2	—
	2	14.1	12.9	11.8	—
	3	14.0	12.2	11.8	—
	4	14.5	13.0	12.0	—
Oil	1	12.0	11.1	10.6	—
	2	13.1	12.0	11.1	—
	3	13.1	11.9	11.1	—
	4	12.0	11.2	10.9	—
Para.	1	13.0	15.2	13.2	—
	2	12.2	11.2	10.2	—
	3	11.5	11.0	10.2	—
	4	12.0	10.1	10.0	—
Date:		28/06/77			
Control	1	20.7	17.7	16.7	—
	2	20.9	20.8	18.5	—
	3	20.0	18.1	17.8	—
	4	22.2	18.8	18.0	—
No Veg.	1	22.8	19.1	17.0	—
	2	19.2	17.2	16.2	—
	3	25.9	22.0	19.0	—
	4	23.9	20.9	18.9	—
Oil	1	17.5	15.8	14.9	—
	2	19.5	17.5	16.9	—
	3	18.9	16.5	16.0	—
	4	19.5	17.6	17.0	—
Para.	1	24.9	21.2	18.8	—
	2	19.0	17.5	16.9	—
	3	20.8	19.0	17.9	—
	4	21.0	19.2	17.9	—
Date:		12/08/77			
Control	1	17.0	16.5	16.1	—
	2	17.0	16.0	15.5	—
	3	16.2	15.5	14.9	—
	4	17.1	16.0	14.9	—
No Veg.	1	18.8	17.0	16.2	—
	2	17.2	17.0	16.2	—
	3	18.2	17.2	16.9	—
	4	17.8	17.0	16.2	—
Oil	1	16.0	15.8	15.2	—
	2	16.8	15.8	15.2	—
	3	16.0	15.3	15.0	—
	4	17.2	15.9	15.2	—
Para.	1	18.8	17.2	16.8	—
	2	17.0	15.8	15.0	—
	3	16.5	15.9	15.2	—
	4	15.9	15.0	14.9	—

APPENDIX B. ELLERSLIE OIL EXPERIMENT, 1977

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11. Arthropod Enumeration: Comparison of effect of treatment on the soil fauna.

Date: 26/04/77

Treatment	Rep.		#Collembola m^{-2}	#Mites m^{-2}
Control	1	(3-6 cm)	6.1×10^4	7.2×10^5
	2	(3-6 cm)	3.2×10^6	5.6×10^6
	3	(3-6 cm)	6.2×10^4	5.6×10^5
	4	(3-6 cm)	1.8×10^4	4.3×10^5
No Veg.	1	(3-6 cm)	6.9×10^4	8.6×10^5
	2	(3-6 cm)	6.9×10^4	8.8×10^5
	3	(3-6 cm)	3.9×10^5	1.5×10^6
	4	(3-6 cm)	2.4×10^4	2.9×10^6
Oil	1	(3-6 cm)	1.9×10^5	7.7×10^5
	2	(3-6 cm)	7.8×10^4	2.3×10^5
	3	(3-6 cm)	4.9×10^4	1.8×10^5
	4	(3-6 cm)	3.2×10^5	3.9×10^5
Para.	1	(3-6 cm)	1.5×10^5	5.0×10^5
	2	(3-6 cm)	Data destroyed by fungi.	
	3	(3-6 cm)	Data destroyed by fungi.	
	4	(3-6 cm)	Data destroyed by fungi.	

APPENDIX B. ELLERSLIE OIL EXPERIMENT, 1977

12. The Collembola and mites found in the Ellerslie soil on three consecutive sampling dates during the 1977 sampling season. Samples were taken to a depth of 12 cm and divided into 3 cm intervals.

Treatment	Date: Depth (cm)	3 /06 /77 #Collembola m^{-2} (x 10^4) 1	2	3	4	#Mites m^{-2} (x 10^4) 1	2	3	4	30 /06 /77 #Collembola m^{-2} (x 10^4) 1	2	3	4	#Mites m^{-2} (x 10^4) 1	2	3	4	12 /08 /77 #Collembola m^{-2} (x 10^4) 1	2	3	4	#Mites m^{-2} (x 10^4) 1	2	3	4
Control	0- 3	18.0	26.0	—	9.7	150.0	160.0	—	140.0	5.6	2.1	1.1	2.3	130.0	120.0	45.0	780.0	52.0	17.0	23.0	11.0	460.0	150.0	330.0	110.0
	3- 6	5.2	29.0	8.2	8.8	31.0	170.0	36.0	110.0	5.3	9.7	24.0	3.0	83.0	76.0	130.0	45.0	31.0	13.0	15.0	8.9	230.0	30.0	71.0	53.0
	6- 9	5.2	12.0	6.2	1.0	52.0	76.0	40.0	41.0	7.4	11.0	16.0	8.7	74.0	59.0	62.0	32.0	21.0	6.2	5.9	3.3	76.0	38.0	45.0	29.0
	9-12	4.5	13.0	7.8	—	82.0	92.0	45.0	—	9.5	5.3	19.0	7.8	94.0	65.0	140.0	61.0	1.9	11.0	13.0	4.0	33.0	88.0	18.0	42.0
No Veg.	0- 3	8.0	14.0	15.0	11.0	97.0	89.0	170.0	76.0	2.6	1.2	5.0	2.3	130.0	170.0	68.0	80.0	26.0	2.5	7.3	30.0	86.0	100.0	110.0	92.0
	3- 6	12.0	5.1	4.3	2.1	37.0	37.0	44.0	40.0	17.0	2.1	1.2	11.0	94.0	40.0	45.0	110.0	11.0	15.0	—	4.7	39.0	67.0	—	140.0
	6- 9	7.8	5.4	7.6	6.1	45.0	53.0	82.0	51.0	15.0	1.0	4.2	28.0	49.0	23.0	28.0	270.0	23.0	23.0	22.0	27.0	50.0	110.0	130.0	160.0
	9-12	8.5	3.0	10.0	7.2	27.0	42.0	91.0	67.0	11.0	26.0	9.3	13.0	58.0	62.0	58.0	83.0	16.0	23.0	300.0	11.0	99.0	69.0	140.0	80.0
Oil	0- 3	21.0	9.0	7.8	11.0	91.0	130.0	120.0	160.0	5.8	2.7	—	5.0	28.0	23.0	—	47.0	12.0	8.3	22.0	2.2	95.0	23.0	76.0	41.0
	3- 6	6.9	6.8	13.0	1.2	69.0	54.0	57.0	30.0	11.0	—	17.0	8.1	37.0	—	58.0	28.0	18.0	14.0	15.0	12.0	160.0	51.0	34.0	36.0
	6- 9	6.5	4.5	5.7	4.8	140.0	41.0	78.0	18.0	9.4	17.0	9.0	12.0	45.0	49.0	50.0	110.0	5.5	15.0	18.0	—	54.0	51.0	37.0	—
	9-12	2.6	7.8	12.0	3.6	18.0	37.0	75.0	34.0	16.0	10.0	16.0	2.0	66.0	68.0	110.0	28.0	6.2	13.0	5.3	11.0	72.0	64.0	37.0	70.0
Para.	0- 3	8.7	2.7	21.0	17.0	51.0	73.0	56.0	63.0	5.9	—	1.1	3.1	46.0	—	37.0	17.0	20.0	22.0	6.9	12.0	120.0	88.0	63.0	120.0
	3- 6	3.4	7.4	6.4	7.4	48.0	36.0	100.0	46.0	7.1	5.5	6.9	2.1	66.0	28.0	41.0	79.0	—	12.0	2.4	17.0	—	42.0	36.0	46.0
	6- 9	6.3	—	9.0	3.0	34.0	—	100.0	43.0	7.1	6.2	21.0	4.1	46.0	50.0	73.0	39.0	3.2	11.0	10.0	3.5	43.0	57.0	53.0	43.0
	9-12	6.3	—	12.0	5.9	39.0	—	110.0	52.0	8.9	5.6	13.0	—	51.0	31.0	130.0	—	7.5	23.0	10.0	4.4	23.0	100.0	37.0	34.0

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Ellerslie: Gleyed Eluviated Black Chernozem

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13. Determination of gravimetric moisture percentage for the Ellerslie LFH horizons.

Date:		16/06/77	30/08/77
Sample	**Depth**		
1	0- 3 cm	53.6	70.4
	3- 6 cm	45.5	82.4
	6- 9 cm	43.7	100.5
	9-12 cm	36.5	90.2
2	0- 3 cm	25.4	--
	3- 6 cm	40.6	--
	6- 9 cm	46.3	--
	9-12 cm	33.0	--
3	0- 3 cm	37.5	42.0
	3- 6 cm	29.5	49.0
	6- 9 cm	23.3	33.6
	9-12 cm	13.0	35.0
4	0- 3 cm	28.8	38.6
	3- 6 cm	33.0	90.5
	6- 9 cm	23.5	34.0
	9-12 cm	44.7	30.7
5	0- 3 cm	27.4	46.4
	3- 6 cm	10.0	42.7
	6- 9 cm	--	47.6
	9-12 cm	50.6	48.4
6	0- 3 cm	36.0	83.3
	3- 6 cm	34.5	88.5
	6- 9 cm	36.2	55.6
	9-12 cm	51.7	67.6

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Ellerslie: Gleyed Eluviated Black Chernozem

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14. pH (0.01 M $CaCl_2$) (Raw Data). 15. Total Carbon (Raw Data).

Sample	Depth	pH	Total Carbon* ugms C/gm O.D. soil
1	0- 3 cm	7.2	280,260
	3- 6 cm	6.8	250,230
	6- 9 cm	6.5	230,280
	9-12 cm	6.6	250,230
2	0- 3 cm	7.7	260,200
	3- 6 cm	6.9	230,200
	6- 9 cm	6.7	180,200
	9-12 cm	6.7	110,110
3	0- 3 cm	7.1	220,250
	3- 6 cm	6.8	210,250
	6- 9 cm	7.1	210,250
	9-12 cm	6.7	110,110
4	0- 3 cm	7.1	220,140
	3- 6 cm	6.4	120,160
	6- 9 cm	6.4	170,160
	9- 12 cm	6.5	70,800
5	0- 3 cm	6.8	260,270
	3- 6 cm	6.8	190,250
	6- 9 cm	6.7	230,330
	9-12 cm	6.6	350,250
6	0- 3 cm	6.6	270,260
	3- 6 cm	6.9	230,270
	6- 9 cm	6.1	250,280
	9-12 cm	6.0	300,270

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* Duplicate samples.

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Ellerslie: Gleyed Eluviated Black Chernozem

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16. Bacterial counts.

Date:		16/06/77					30/08/77				
		#Bacteria/gm O.D.soil (x 10^6)					#Bacteria/gm O.D.soil (x 10^6)				
Analytical Rep:		1	2	3	4	5	1	2	3	4	5
Sample	**Depth**										
1	0- 3 cm	34	27	29	31	37	110	100	37	65	25
	3- 6 cm	2	1	1	1	1	192	53	271	138	126
	6- 9 cm	39	36	18	36	25	25	29	51	216	50
	9-12 cm	2	2	2	2	2	62	60	40	46	50
2	0- 3 cm	90	75	121	83	81	--	--	--	--	--
	3- 6 cm	40	33	37	30	35	--	--	--	--	--
	6- 9 cm	212	--	--	--	--	--	--	--	--	--
	9-12 cm	147	--	19	47	49	--	--	--	--	--
3	0- 3 cm	81	118	77	99	78	25	--	--	67	92
	3- 6 cm	24	28	19	20	25	29	35	26	29	41
	6- 9 cm	32	41	50	55	47	18	23	21	21	21
	9-12 cm	43	46	44	31	46	16	35	47	27	10
4	0- 3 cm	51	99	103	82	67	49	56	58	46	47
	3- 6 cm	45	41	31	32	45	99	176	274	116	108
	6- 9 cm	66	58	69	73	67	43	36	39	33	29
	9-12 cm	37	31	33	18	40	40	49	65	55	31
5	0- 3 cm	90	64	124	79	90	33	29	31	19	51
	3- 6 cm	48	59	80	77	65	64	40	36	36	48
	6- 9 cm	38	34	26	43	--	74	88	61	76	88
	9-12 cm	58	40	35	55	41	62	36	45	83	79
6	0- 3 cm	149	136	74	83	76	31	34	33	29	32
	3- 6 cm	49	50	54	61	59	54	204	39	40	18
	6- 9 cm	89	83	76	74	86	71	97	68	70	80
	9-12 cm	68	74	86	65	43	88	71	79	77	77

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Ellerslie: Gleyed Eluviated Black Chernozem

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17. The number of Collembola and mites found in the Ellerslie LFH horizons.

Date: 16/06/77

Sample	Depth	#Collembola m^{-2} ($x 10^5$)	#Mites m^{-2} ($x 10^5$)
1	0- 3 cm	3	30
	3- 6 cm	1	30
	6- 9 cm	3	10
	9-12 cm	4	20
2	0- 3 cm	3	10
	3- 6 cm	1	10
	6- 9 cm	3	50
	9-12 cm	1	10
3	0- 3 cm	1	5
	3- 6 cm	1	10
	6- 9 cm	1	6
	9-12 cm	1	10
4	0- 3 cm	3	30
	3- 6 cm	3	50
	6- 9 cm	2	20
	9-12 cm	2	40
5	0- 3 cm	1	8
	3- 6 cm	-	-
	6- 9 cm	4	20
	9-12 cm	3	50
6	0- 3 cm	10	30
	3- 6 cm	5	30
	6- 9 cm	10	50
	9-12 cm	3	30

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Ellerslie: Mineral Horizons (Raw Data)

18. Physico-chemical analysis of the Ellerslie mineral horizon.

Sample	Rep.	% Moisture (17/09/77)	Soil pH (0.01 M $CaCl_2$)
1	1	20.2	6.2
	2	20.0	6.4
	3	19.7	6.3
	4	20.1	6.5
2	1	16.1	6.5
	2	15.9	6.4
	3	15.9	6.4
	4	16.0	6.3
3	1	20.3	6.3
	2	20.2	6.3
	3	21.0	6.3
	4	19.9	6.2

19. Bacterial numbers of the Ellerslie mineral horizons determined in PCA agar.

Rep.	#Bacteria m^{-2} (x 10^5)
1	34
2	28
3	48

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Ellerslie: Mineral Horizons

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20. The number of Collembola and mites in the Ellerslie mineral horizon.

Sample	Depth	#Collembola m^{-2} (x 10^4)	#Mites m^{-2} (x 10^5)
		16/06/77	
1	0- 3 cm	5	6
	3- 6 cm	1	3
	6- 9 cm	1	6
	9-12 cm	2	6
2	0- 3 cm	-	-
	3- 6 cm	-	-
	6- 9 cm	-	-
	9-12 cm	-	-
3	0- 3 cm	1	10
	3- 6 cm	1	3
	6- 9 cm	1	20
	9-12 cm	1	30
4	0- 3 cm	1	2
	3- 6 cm	1	5
	6- 9 cm	1	5
	9-12 cm	1	10
5	0- 3 cm	1	3
	3- 6 cm	1	10
	6- 9 cm	3	30
	9-12 cm	1	6
6	0- 3 cm	4	20
	3- 6 cm	5	20
	6- 9 cm	1	10
	9-12 cm	1	3
		17/09/77	
1	0- 3 cm	20	60
	3- 6 cm	2	60
	6- 9 cm	20	90
	9-12 cm	-	90
2	0- 3 cm	2	30
	3- 6 cm	60	2
	6- 9 cm	-	10
	9-12 cm	-	3
3	0- 3 cm	60	200
	3- 6 cm	2	30
	6- 9 cm	20	30
	9-12 cm	30	60
4	0- 3 cm	2	20
	3- 6 cm	-	60
	6- 9 cm	2	60
	9-12 cm	90	60
5	0- 3 cm	10	60
	3- 6 cm	30	3
	6- 9 cm	-	-
	9-12 cm	-	-
6	0- 3 cm	20	90
	3- 6 cm	60	30
	6- 9 cm	2	30
	9-12 cm	-	2

APPENDIX C. VARIATIONS IN WATER-SOLUBLE ORGANIC MATTER AND SOIL FAUNA OF THREE ALBERTA SOILS.

Breton Gray Luvisol

21. The gravimetric moisture percentage and pH (0.01 M $CaCl_2$) for the Breton soil determined for four depths.

Sample	Depth	% Moisture	pH
1	0- 3 cm	226.8	6.2
	3- 6 cm	64.0	4.4
	6- 9 cm	24.5	5.1
	9-12 cm	18.1	5.5
2	0- 3 cm	139.6	6.3
	3- 6 cm	65.6	5.6
	9- 9 cm	27.7	5.7
	9-12 cm	22.2	5.3
3	0- 3 cm	244.1	5.3
	3- 6 cm	105.2	6.4
	6- 9 cm	49.7	6.8
	9-12 cm	24.3	6.7
4	0- 3 cm	175.0	6.1
	3- 6 cm	188.5	5.9
	6- 9 cm	152.2	6.3
	9-12 cm	37.6	7.0

22. Bacterial numbers of the Breton soil as determined on PCA agar.

Depth	Bacterial Numbers (x 10^4) X ± S.D.
0- 3 cm	5,000 ± 0.7
3- 6 cm	26 ± 0.05
6- 9 cm	40 ± 0.06
9-12 cm	33 ± 0.06

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